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COMPARISON OF AMERICAN AND EUROPEAN LOWER ORDOVICIC FORMATIONS[1]

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CONTENTS

[1] Manuscript received by the Secretary of the Geological Society August 25, 1916.
This is the first of a series of comparative studies of the European and American Paleozoic, based on investigations and collections made by the writer during eight months' sojourn in northern Europe in 1910.

Introduction

Geologists familiar with the formations of both hemispheres will in general agree that while Europe must always serve as the type region for the Mesozoic and Cenozoic formations, the North American Paleozoic should be considered the standard by which other deposits of that age must be judged. In no other known region is there such an extensive development of the older formations, both in their marine and continental phases, and in no other known portion of the world is the record so clearly preserved as in the Paleozoic rocks of the greater part of the North American continent. This is especially true of the earlier systems, which have not only a slight representation over much of Europe, but are for the most part strongly disturbed; or, where not so affected, as in the Russian region, are in large part covered by comparatively recent surface deposits. This is emphasized by the extent of the treatment accorded the several divisions of the column in the standard European treatises. Thus, Kayser in his "Lehrbuch der Geologischen Formationskunde," fourth edition, devotes 273 pages to the Paleozoic and 400 pages to the remainder of the column, above the Paleozoic, the Paleozoic thus receiving about 40 per cent of the whole. Of the 273 pages given to the Paleozoic, 30 are devoted to the Cambric, 55 to the Ordovicic and Siluric, 60 to the Devonic, 66 to the Carbonic (including the Mississippic), and 61 to the Permic. Of the 217 pages devoted to the Mesozoic, 81 go to the Triassic, 60 to the Jurassic, and 76 to the Cretacic, including the Comanchic of American usage. Haug in his "Traité de Géologie" gives 34 pages to the Cambric, 50 to the Ordovicic and Siluric, 71 to the Devonic, 105 to the Anthracolithic (Mississippic-Permic), or a total of 260 pages to the Paleozoic. To the Triassic he gives 81, to the Jurassic 224, and to the Cretacic (inclusive of Comanchic) 244, making a total of 549 to the Mesozoic, or more than double that given to the Paleozoic. The Tertiary (Cenozoic) is discussed in 363 pages and the Quaternary (Psychozoic) in 162 pages. The Paleozoic thus receives 19.5 per cent, or about one-fifth of the space devoted to the entire post-Algonkic history of the earth.

In the large volume on the Paleozoic of the world, in the Lethæa Geognostica, Frech devotes 45 pages to the Cambric, 56 to the Ordovicic-Siluric, 140 to the Devonic, and 408 pages to the remainder of the Paleozoic. The Triassic is treated in a separate volume of 561 pages, while the higher formations promise to be treated with similar generosity.

If we now look at the volumes of Chamberlin and Salisbury, where the American standpoint is taken, we find that the Paleozoic has devoted to it 460 pages, of which 86 go to the Cambric, 64 to the Ordovicic, 50 to the Siluric, 78 to the Devonic, 43 to the Mississippic, 80 to the Pennsylvanic, and 59 to the Permic. The Triassic is considered in 58 pages, the Jurassic in 47 pages, the Comanchic in 31 pages, and the Cretacic proper in 54 pages, making a total of 190 for the Mesozoic. The Tertiary receives 136 pages and the Quaternary 216 pages; thus the Paleozoic comprises nearly 46 per cent of the entire treatise on post-Algonkic systems.

In the fourth edition of Dana's "Manual" 278 pages are devoted to the Paleozoic, 141 to the Mesozoic, and 158 to the Tertiary and Quaternary, the Paleozoic receiving thus 49 per cent, or nearly one-half, of the space given to the entire post-Archean portion of the section on Historical Geology. If the various treatises were strictly devoted each to its own country, the discrepancies would be even more marked than they are.

In the succeeding pages of this paper some of the Lower Paleozoic formations of Europe are considered in the light of the knowledge gained by a study of American formations of the same age. My field studies in Europe were made during the last eight months of the year 1910, and the material then collected has been studied at intervals since that time in the laboratory. While considering the lithologic and faunal characters of the several formations, emphasis will also be laid on the evidences for the occurrences in the European field of the disconformities and hiatuses known to separate certain American formations, and which may owe their existence to diastrophic movements.

Lower Ordovicic of Europe and North America compared

The classification of the Ordovicic rocks of western Europe is generally based on the British succession, since that was the first to be determined and defined. As is well known, these rocks were called by Sedgwick Upper Cambrian, and by Murchison, Lyell, Phillips, and others, Lower Silurian. Even the *Lingula flags* and the *Menevian* were included by Jukes (1863) in the Lower Silurian or Cambro-Silurian, while Murchison (1868) called them "Primordial Silurian." The Geological Survey in

1865 likewise included them in the Lower Silurian, thus leaving only the Harlech grits to represent the Cambrian. Ramsay in 1878 went even further, including all the formations in the Silurian—a proceeding in which he was anticipated by Barrande[2] and followed by some recent writers, notably Bernard (1895). Lapworth's classification of 1879 has now become the standard for British as well as American geologists, though continental geologists still retain Silurian for the two upper divisions, referring to them either as Lower and Upper Silurian, Unter und Ober Silur (Kayser, etcetera), or as Ordovicic and Gotlandic (Haug and some Swedish geologists).[3]

The Tremadoc rocks of Wales were considered by Barrande as transition beds between those carrying the first (Cambric[4]) and those holding the second (Ordovicic) faunas. They were included in the Cambrian by Lapworth, and have there been generally retained by British geologists. On the continent of Europe, however, the rocks of this age are now being generally classed as Lower Ordovicic (tieferes Untersilur), and the dividing line is drawn at the base of the *Dictyonema flabelliforme* shales.

The British subdivisions of the Ordovicic, as now used, fall into the following five groups, in descending order:

5. Ashgillian or Upper Bala.
4. Caradocian or Middle Bala.
3. Llandeilan or Lower Bala.
2. Arenigian or Arenig.
1. Tremadocian or Tremadoc.

From the point of view of continuous sedimentation, these five groups may be combined into three divisions, separated from one another and from the succeeding and sometimes the preceding ones by disconformities (more rarely unconformities). These combinations are (*a*) the Tremadocian and Arenigian, (*b*) the Llandeilan and Caradocian, and (*c*) the Ashgillian. In a general way these correspond to (*a*) our Beekmantownian (including the Dictyonema beds, Potsdam, and Little Falls horizons), (*b*) our Chazyan and Trentonian (to the top of the Lorraine), and (*c*) our Richmondian. With us, too, these formations are separated

[2] See especially "Du Maintien de la Nomenclature établie par M. Murchison, par M. J. Barrande." Extrait du Compte Rendu Sténographique du Congrès International de Géologie, tenu a Paris du 29 au 31 août et du 2 au 4 Septembre, 1878.

[3] For a summary of the early history of classification see J. E. Marr: The classification of the Cambrian and Silurian rocks. Geological Magazine, decade ii, vol. viii, pp. 245-250. June, 1881.

[4] The terms *Cambric, Ordovicic,* and *Siluric* are used in the sense generally employed in this country, while Cambrian of Sedgwick refers to the series from the Harlech to the Bala, inclusive. Silurian has a different value according to the author employing it, from Barrande and Ramsay, who include the Cambric, Ordovicic, and Siluric in it, to Sedgwick and Lapworth, who use it in the sense of our Siluric only.

by widespread disconformities, and such breaks in sedimentation also succeed, and probably very generally precede, the series. That these breaks in the sedimentary record are due to extensive retreatal or negative eustatic movements of the sea seems unquestionable, and on this account it would appear that such breaks furnish valuable datum planes for delimiting definite divisions of the stratigraphic scale inclosed between them. It must, however, always be borne in mind that the retreat of the sea and its readvance occupied a considerable time interval, and that during such movements sedimentation continued longer and recommenced earlier in the region of later emergence during retreat, and of earlier submergence during readvance, of the sea—that is, in the region farthest removed from the shoreline at the beginning of the retreatal movement—than it did in this shoreline region. Concomitantly, the region of first emergence and last resubmergence would suffer most erosion. Again, it must not be forgotten that the borders of the emerging continents, as well as occasionally some sections within the continents, still remained submerged at the end of the retreatal movements, and that hence sedimentation there was entirely continuous. Those regions may in many cases be beyond the confines of the present dry-land masses, but in others they are undoubtedly within the present borders of these lands, though erosion during later periods may have removed the record. To use such disconformities as limiting planes for geological systems when unaccompanied by decided changes in faunas seems at present hardly warranted, though it must be conceded that if the exact limits of the retreatal and readvance movement could be determined, provided such movements were everywhere uniform or with but minor oscillations, and if more or less marked faunal changes could be proved to accompany such changes, a very satisfactory and convenient basis for subdivision of the geological column would be furnished. If such a basis could be adopted, the systems would include the deposits formed from the beginning of the transgressive movement to its culmination, and then to the end of the regressive movement. Each system would thus be separable into two divisions, one representing the transgressive and the other the regressive movement. Since such movements were, however, very probably not all of the same magnitude, our systems would be of unequal value; and while some might be sufficiently great to be accompanied by great faunal changes (more or less induced by these physical changes), others might show no such parallel effects in the organic world.

In the case of the formations now included in the Ordovicic, we would have three diastrophic systems—the Tremadoc-Arenig, the Llandeilo-Caradoc, and the Ashgillian. The last of these is the smallest in point

of sedimentation, so far as known, but is accompanied by the most pronounced faunal change, since it marks the appearance of faunal elements generally regarded as typical of the Siluric. The corresponding American systems would be the Beekmantownian (including the Ozarkian, in a modified sense, as the transgressive phase[5]), the Chazy-Trenton, and the Richmondian. As will be shown later, however, the pre-Richmond emergence was not comparable in magnitude to the emergence marking the end of Beekmantown time. Schuchert uses the terms Canadian, Champlainian, and Cincinnatian for these three diastrophic cycles; but in his Cincinnatian he includes what is most certainly a part of the emergence phase of his Champlainian cycle, namely, the Utica shale. The Chazy and Trenton were included by Dana in the first edition of his manual in the Trenton period, which is essentially equivalent to Schuchert's modified Champlainian (not the Champlainian of Clarke and Schuchert, 1899). The Utica and higher beds were placed by Dana in the Hudson period in 1863, but included with the Trenton limestone (inclusive of the Black River and "Birdseye") in the Trenton period in the fourth edition in 1895, when he placed the Chazy within the Canadian. It is in this sense that I here use the term Trentonian, a term essentially equivalent to the English Caradocian.

Lower Ordovicic of North Scotland and its Relation to similar Deposits Elsewhere

GENERAL PETROGRAPHIC AND FAUNAL CHARACTERISTICS

One of the remarkable features of the early Paleozoic rocks of Britain is the striking difference in character and faunas between the Cambric and Ordovicic rocks of the northern and of the southern area. The southern area, which comprises all the regions south of the Scottish Highlands, includes the type regions for the Cambric, Ordovicic, and Siluric formations, which are for the most part developed in their terrigenous facies as quartzites, graywackes, sandstones, and mudstones, while limestones are more rarely represented. The prevailing element of the entombed faunas is furnished by the graptolites, though trilobites are also of frequent occurrence. It is this southern or English fauna which has its close analogue in northeastern North America (New Brunswick, Cape Breton, eastern Newfoundland, eastern New England, etcetera), and the faunas found in these beds must be regarded as representing that of the somewhat expanded Atlantic of that time.

[5] This is the Potsdam period of the first edition of Dana's "Manuai" (1863), which he divided into, 1, *Potsdam epoch,* and 2, *Calciferous epoch.*

The northern development, found in the northwest of Scotland, is totally different from the southern, for mudstones are rare or lacking, and the lithic development comprises sandstones and limestones or dolomites. The faunas are wholly distinct from those of the southern area, this distinction being expressed not only in specific, but far more pronouncedly in generic, differences.

THE NORTHERN SECTIONS

I have studied these formations at various localities in the northwest of Scotland, especially in the vicinity of Durness, and along the rugged shores of Loch Eriboll. The series begins with a great quartzite, generally of pure quartz grains, though the lower part contains much feldspar, while the base consists of a thin conglomerate of coarse and fine fragments. The rock rests either on the old Lewisian gneiss, from the disintegration and decomposition of which the quartzite has been derived, or on an intervening sandstone and conglomerate, the Torridonian, which itself is an earlier, terrestrial derivative from the gneiss.

The total thickness of the basal, sandy, or quartzite series is almost 600 feet. The lower third is cross-bedded and feldspathic, and without fossils, representing a purely terrestrial accumulation. The upper two-thirds is more or less fossiliferous and may represent, in part at least, a seashore accumulation. It abounds in vertical worm-holes, mostly of the types referable to Scolithus, from which a part of the rock received its name of "pipe-rock." The upper part becomes more calcareous, and Salterella, Hyolithes, and Olenellus make their appearance. This portion represents the Lower Cambric division, the fauna being of the Pacific type and like that of the Appalachian trough of North America. The entire series is generally spoken of as the *Eriboll quartzite series,* from its excellent development on the shores of Loch Eriboll. Through the calcareous zones the series grade upward into a pure dolomitic limestone, which goes under the name of the *Durness limestone series,* from the fine exposures found in the vicinity of that village in northwestern Scotland. The lower part of this calcareous series is conformable with the underlying sandstones, with which it forms a continuous depositional unit. The total thickness of this calcareous series is almost 1,500 feet, and it is divisible into the several following groups:

Durness limestone series, 1,500 feet:

- **VII. Durine group.**
- **VI. Croisaphuill group.**
- **V. Balnakiel group.**
- **IV. Sangomore group.**

III. Sailmhor group.
II. Eilean Dubh group.
I. Ghrudaidh group.

Eriboll quartzite series:

	Feet
Serpulite grit	30
Fucoid shales	40–50
Pipe-rock	300
Basal sandstone and conglomerate	200

Unconformity.

Lewisian gneiss or Torridonian sandstone.

The Fucoid shales carry a considerable Lower Cambric fauna, including four species and two varieties of Olenellus, as well as such characteristic species as *Kutorgina* (*Iphidea*) *labradorica* Bill. and others found in the American Lower Cambric of the Appalachian province. The Serpulite grit contains *Salterella maccullochi* (Salter) and *Olenellus lapworthi.* The succeeding Ghrudaith limestone contains three species of Salterella—*S. maccullochi* (Salt), *S. pulchella* Bill., and *S. rugosa* Bill.—the last two being American species. The Salterella are distributed in two bands in the Ghrudaith limestone, one at the base and one almost 30 feet above it. The upper part is mottled dolomite, "the mottling being due to the great abundance of worm-casts of the nature of Planolites."[6]

The Eilean Dubh group of fine-grained, white, flaggy limestones is destitute of fossils, except those markings which have been referred to worm-casts. This appears to have been a shallow-water accumulation with occasional hardening of the layers on exposure and the production of intra-formational breccias. An examination of the beds of this group on Eilean Dubh (The Black Isle), in Balnakiel Bay, near Durness, which I was able to make in 1910, disclosed such a zone about 10 feet thick on the eastern side of the island, continuing with irregular thickness and showing no stratification. The rock is a calcilutite and is succeeded irregularly by a fine calcarenite.

On the west side of the island, just above high-water mark, is an interbedded conglomerate, with worn pebbles of limestone generally less than an inch in diameter, the bed varying in thickness from a few inches to a foot. There is also a green clay streaking the conglomerate in places. The rock above this clay layer likewise appears conglomeratic or brecciated; but this structure is not very distinct, and since the pebbles and matrix are essentially of the same material, it is often difficult to differ-

[6] B. Peach and J. Horne: The geological structure of the northwest highlands of Scotland. Great Britain, 1907.

entiate them. In one place this overlying, pebbly mass is 1 foot and 8 inches thick. The brecciated zone above referred to follows immediately above this conglomerate, thus showing the whole to be a zone of prolonged disturbance. The surface on which the conglomerate rests is on the whole very level, though minor irregularities are noticeable. The following sketch, reproduced from my notebook, shows some of these.

This contact can be traced across the low neck (submerged at high tide) which connects the island with the mainland, its position being at or just below high tide, and the exposure being essentially along the strike of the beds, and thus appearing horizontal. On the mainland it can be traced in the cliff for some distance along the shore of the Kyle of Durness.

The significance of this conglomerate lies in the fact that it marks a period of distinct emergence, followed by erosion and resubmergence of

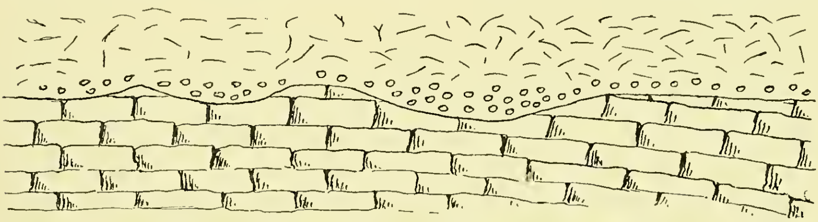

FIGURE 1.—*Disconformable Contact of Lower Ordovicic on Lower Cambric at Eilean Dubh, near Durness, Scotland*

the region. The magnitude of the hiatus here represented is, however, not apparent; from the physical appearances one would be tempted to assign little significance to it. The fact, however, that the beds some distance above carry a typical Lower Ordovicic (Beekmantown) fauna makes it evident that its significance is greater than would at first appear, for the entire Middle and Upper Cambric is here cut out, indicating a period of prolonged exposure and of non-deposition of the later Cambric strata.

It may be added that the physical evidence of a hiatus known to exist in other cases is no more marked than that found here. Such is the case in the Siluro-Devonic contact in sections of western New York, Canada, and Michigan, where the whole Lower Devonic is wanting, as well as a part of the Upper Siluric.

It is possible that this conglomerate marks only a minor emergence, and that the great break between the Lower Cambric and the Lower Ordovicic is somewhat higher. The beds which succeed the conglomerate layer are at first massive, fine, calcarenites, followed by thin-bedded calcilutites, which on weathered surfaces show a fine cross-bedding, such as would be produced by migrating ripples. This is sometimes very marked,

but is always on a small scale. Higher still occur massive beds which show little bedding, but are characterized by a vertical flaking. At the top of this are the brecciated layers.

About 125 feet above the conglomerate, at the top of the first cliff, back of the shore cliff, is an exceedingly irregular line of contact between dolomitic calcarenites and the overlying calcilutites. The following sketch from my notes shows this contact as exposed on a part of the cliff.

It is difficult to decide whether this is a sedimentary contact or represents irregularity of dolomitization of the limestones. The appearance in some cases suggests irregular ridges of dolomite, comparable to the "yardangs" of central Asia, as described by Sven Hedin.[7] The spaces

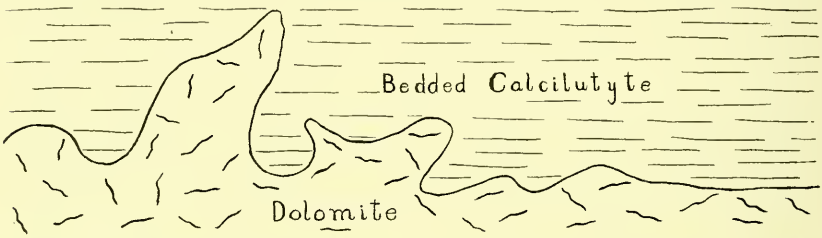

FIGURE 2.—*Irregular Contact between Dolomite and bedded Calcilutite in the Cliffs facing the Kyle of Durness, Scotland*

This may represent the Cambro-Ordovicic disconformity

between the ridges are filled with fine, stratified lime mud. This often shows brecciation, and fragments of dolomite are frequently included in the limestone, resembling broken-off masses.

Somewhat higher begin the beds of the Sailmhor group, which comprise for the most part strongly mottled dolomites, to which the local name, *leopard stone,* is applied. The rock has the appearance of a breccia composed of dark and light angular fragments. The brecciation is probably the result of dolomitization. Much chert is present, but the rock as a whole shows little evidence of stratification. This rock has furnished the following fossils:[8]

1. *Isotelites canalis* (?) Conrad.
2. Murchisonia sp.
3. *Pleurotomaria* (Euconia) *etna* Bill.
4. *P.* (Euconia) *ramsayi* Bill.
5. Cyrtoceras, two species.
6. Orthoceras sp.

[7] See illustration reproduced in my Principles of Stratigraphy, p. 53, fig. 13.
[8] Peach and Horne: Loc. cit., p. 629.

Of these, numbers 1 and 3 have been obtained from the Beekmantown of Newfoundland (1 from zones F-M and 3 from zones G-H of Billings), while number 4 was originally described from the Lower Beekmantown (Romaine) of the Mingan Islands.

It is thus evident that the lowest fossiliferous beds succeeding the indicated break in the series have a typical Beekmantown fauna, and although these and the succeeding members of the Durness limestone series are classed as Middle and Upper Cambric by British geologists, it is clear that they belong in the base of the Ordovicic, and that Middle and Upper Cambric are wanting here. The conditions are thus the same as those found in western Newfoundland and in the Saint Lawrence Valley, as well as in the region east of Lake Champlain, where Lower Ordovicic beds follow on Lower Cambric. Moreover, it is evident that the faunal characteristics of the Durness series ally it with the Beekmantown limestones of western Newfoundland rather than with those of any other British or continental formation. The close correspondence between the North Scottish and American deposits, expressed even more strongly in the succeeding members of the Durness group, was pointed out as early as 1859 by Salter, and has been recognized by every one since. Yet these beds have always been referred to the Cambric by British geologists, even though some of the fossils found in the higher beds are of Black River types.

No fossils have been found in the Sangomore dolomites, but the Balnakiel and Croisaphuill groups contain a considerable assemblage of organisms, all of which I had the opportunity of studying in the collections of the Edinburgh Museum through the courtesy of the custodians. The specifically identified forms are given in the following:

TABLE OF ORDOVICIC SPECIES FROM THE DURNESS LIMESTONE

(Modified from Peach and Horne)

	Balnakiel group.	Croisaphuill group.	Durine.	Skye.	American occurrence.
SPONGIDA, etcetera:					
1. *Archæoscyphia minganensis* (Bill.)	×	×	....	×	Beekmantown (Romaine), Mingan Islands.
2. *Calathium anstedti* Bill.	×	....	....	×	Zone H, Newfoundland.
3. *Calathium ? pannosum* Bill.	....	....	....	×	Point Levis, Quebec.
4. *Receptaculites calciferus* Bill.	....	....	....	×	Beekmantown (Romaine), Mingan Islands.
5. *Receptaculites elegantulus* Bill.	....	....	....	×	Beekmantown (Romaine), Mingan Islands.
TRILOBITA:					
6. *Bathyurus (Petigurus) nero* Bill.	....	×	....	....	Zones F, G, H, and N of Billings, Newfoundland.
7. *Conocoryphe chippewaensis* Owen.	×	×	....	....	Lower Cambric, New York.
BRACHIOPODA:					
9. *Camerella (Swantonia) antiquata* Bill.?	×	×	....	....	Lower Cambric, Vermont.
10. *Orthisina (Nisusia) festinata* Bill.?	....	×	....	×	Lower Cambric, Vermont, New York, Labrador, etc.
11. *Billingsella ? grandæva* (?) Bill.	....	....	....	×	Beekmantown (Romaine), Mingan Islands.
12. *Orthis striatula* Salter	×	....	....	×	
PELECYPODA:					
13. *Euchasma blumenbachi* Bill.	×	×	....	×	Zones G and H, Newfoundland.
and varieties	×	×	....	×	(Also Mingan Islands.)
GASTROPODA:					
14. *Bellerophon (Oxydiscus) palinurus?* Bill.	....	×	....	....	Beekmantown, Canada East.
15. *Holopea leiosoma* Bill.	....	×	....	....	Number 3 limestone, Point Levis, Quebec.
16. *H. ophelia* Bill.	×	....	....	×	Zone L, Newfoundland.

17. *Maclurea acuminata* Bill	....	....	....	×	Zones K-M, Newfoundland.
18. *Maclurea crenulata* Bill	×	×	....	×	Zones J, K, L, and M, Newfoundland.
19. *M. emmonsi* Bill	....	....	....	×	Zones J, K, L, and M, Newfoundland.
20. *M. oceana* Bill	×	×	....	×	Zones F, G, H, Newfoundland. Beekmantown.
21. *M. peachi* Salter	×	×	....	×	
other species	×	×	....	×	Newfoundland.
22. *Murchisonia* (*Ectomaria*) *adelina* Bill.	×	×	....	×	Zone G. Beekmantown, Newfoundland.
23. *M.* (*Hormotoma*) *anna* Bill	×	×	....	×	Beekmantown, Mingan Islands.
24. *M.* (*Hormotoma*) *antiqua* Donald.	....	×	....	....	
25. *M.* (*Hormotoma*) *artemesia* Bill.	×	×	....	×	Beekmantown, Canada, Virginia.
26. *M.* (*Lophospira*) *augustina?* Bill.	×	....	....	×	Zones H-N, Newfoundland, Trenton, Minnesota.
27. *M.* (*Hormotoma*) *bellicincta* Hall.	×	....	....	×	Trenton, New York, Minnesota.
28. *M.* (*Lophospira*) *borealis* Donald.	×	×	....	×	Trenton, Alumette Island, Canada.
29. *M.* (*Hormotoma*) *gracilis* Hall	×	×	×	×	Black River to Richmond, United States, and Canada.
30. *M.* (*Hormotoma*) *gracillima* Salt.	×	×	×	×	
31. *Murchisonia* (*Cœlocaulus*) *linearis* Bill.	×	×	....	....	Beekmantown, Mingan Islands.
32. *M.* (*Ectomaria*) *pagoda* Salt	×	....	....	×	Black River, Ottawa, Canada; New York, Minnesota, Wisconsin.
33. *M.* (*E.*) *pagoda* var. *orientalis* Donald.	....	×	....	×	
34. *M.* (*E.*) *pagoda* var. *peachi* Donald	×	×	....	×	
35. *Ophileta compacta* Salt	×	×	....	×	Beekmantown of Quebec.
36. *O. complanata* Vanux	....	....	....	×	Beekmantown, New York. Vermont. Pennsylvania, Maryland, Virginia, etcetera.
37. *O. nerine* Bill	....	....	....	×	Zone F. Newfoundland.
38. *Pleurotomaria* (*Trochonema*) ? *calphurnia* Bill.	×	×	....	×	Newfoundland.
39. *Pleurotomaria* var. 1	×	×	....	×	
39*a*. *Pleurotomaria* var. 2	×	×	....	×	
40. *Pl. arabella?* Bill	×	....	....	....	Beekmantown, Canada.
41. *Pl.* (*Euconia*) *beekmanensis ?* Whitf.	×	×	....	×	Beekmantown, New York.
42. *Pl. calcifera* Bill	×	×	....	×	Beekmantown, Canada.
43. *Pl. canadensis* Bill	×	....	....	....	Beekmantown. Canada. Mingan Islands.
44. *Pl.* (*Eotomaria*) *dryope* Bill	×	....	....	....	Black River, Ottawa; Minnesota. Missouri, Tennessee.

	Balna-kiel group.	Croisa-phuill group.	Durine.	Skye.	American occurrence.
45. *Pl.* (*Euconia*) *etna* Bill	....	×	....	....	Zones G, H, Newfoundland.
46. *Pl. gregaria* Bill	×	×	....	....	Beekmantown, Canada; Mingan Islands.
47. *Pl.* (*Raphistomina*) *laurentina* Bill.	....	×	....	×	Beekmantown (Romaine), Mingan Islands.
48. *Pl.* (*Euconia*) *ramsayi* Bill	....	×	....	×	Beekmantown (Romaine), Mingan Islands.
49. *Pl.* (*Helicotoma*) *spinosa* (Salt.)	×	×	....	....	Black River, Ottawa River, Canada.
50. *Pl. thule* Salt	×	....	....	....	
51. *Pl.* (*Sinuopea*) *turgida* Hall	....	×	....	×	Little Falls dolomite, New York; Beekmantown, Iowa.
CEPHALOPODA:					
52. *Orthoceras arcuoliratum* Hall	×	....	....	....	Trenton, New York.
53. *O. vaculoides* Blake	×	....	....	×	
54. *O. durinum* Blake	×	....	....	×	
55. *O.* (*Actinoceras*) *mendax* Salt	×	×	....	×	Newfoundland? Mingan Islands?
56. *O.? pertinens* Blake	×	×	....	×	
57. *O.? undulostriatum* Hall	×	×	....	....	Trenton, New York.
58. *Cycloceras olorus* (Hall)	×	×	....	....	Black River, Wisconsin, Minnesota; Trenton, New York; Minnesota.
59. *Pilocerus invaginatum* Salt	×	×	....	×	Beekmantown, Newfoundland; Fort Cassin.
60. Trocholites, 4 species.					
INCERTÆ SEDES:					
61. Planolites	×	×	....	×	Beekmantown.

DISCUSSION

Of these 60 species, 3 (numbers 7, 9, and 10) are reported from the Lower Cambric. These include one trilobite, doubtfully identified, and two brachiopods. The trilobite was not to be found in the Edinburgh collection; the brachiopod identified as *Camarella* (*Swantonia*) *antiquata* Bill. is a small inner mold, with characters inconclusive. Walcott does not cite it from the Durness limestone in his revision of that species. The same is true of *Orthisina* (*Nisusia*) *festinata* Bill. Of the identified species, 29, or 47.5 per cent, occur in the Beekmantown of eastern Canada or New York; 5, or about 8.5 per cent, occur in beds referred to the Chazy in Newfoundland, but which may also belong to the Beekmantown; 5, or about 8.5 per cent, are found in the Black River beds of America, and 4, or about 6.5 per cent, in the Trenton and higher beds of the American Ordovicic.

In spite of the 25 per cent of species identified with Chazy or younger American forms, the fauna is probably a unit, for the material identified is as often as not from the lower of these beds. It is not impossible, however, that the higher part of the Croisaphuill group may include a Chazyan horizon, there being in that case a hiatus between the Chazyan and the Beekmantown portion of this group. The only fossils listed from the Durine group are *Hormotoma gracilis*, a typical American Black River to Richmond species, and *H. gracilima* Salter. This series may represent Black River or younger Ordovicic horizons of the East American type. It should, however, be remembered that the preservation of these forms is generally such as to render absolute identification difficult, if not impossible.

As has been stated, the Scottish series finds its counterpart in the deposits of western Newfoundland, as shown at Bonne Bay, Table Head, and Cowhead. The lower part of this series, including divisions A-C, with a total of 2,020 feet, represents the Lower Cambric and carries the Olenellus fauna. This part is therefore the analogue of the Eriboll quartzites and the Serpula grits of northern Scotland. Divisions D to H, inclusive, with a thickness of 1,839 feet, represent the Beekmantown. The contact between D and C is shown in Bonne Bay, but its detail has not been worked out. From 250 to 300 feet below the top of Division C, as defined by Logan and Billings, occurs a white quartzite in beds of from 2 to 3 feet thick and interstratified with pyritiferous magnesian limestones, which constitute one-fourth of the mass. This quartzite may mark the actual contact and conceal the hiatus between the Lower Cambric and the Lower Ordovicic strata. The beds below this sandstone are shales and limestones carrying the Olenellus fauna, while those above are

mostly calcareous, the Beekmantown fauna appearing some 400 feet above the top of the quartzite.

The highest member of the Newfoundland series, which is commonly included in the Beekmantown, is Division H, seen at Table Head, where 100 feet of limestone with *Orthis electra ?, Maclurea matutina ?,* and *Orthoceras piscator* are shown. The next 165 feet are concealed, and here falls the contact with divisions I to M, which are placed in the Upper Chazyan and Black River. From the fact, however, that the typical Beekmantown species *Maclurea matutina* and *Dalmanella electra* are also found in I and K, it is suggested that these two divisions also belong to the Beekmantown. Logan, however, says (1863 Report, page 871): ". . . The chief part of the species of the remaining gastropods and cephalopods [of divisions K, L, and part 1 of M] are so closely allied to some of the common forms of the Trenton group that it scarcely appears doubtful that they are the same. The most striking resemblances are to *Orthoceras bigsbyi* and *O. allumettense* of the Birdseye and Black River, and to *Murchisonia gracilis, M. bellicincta,* and *M. perangulata* of the Trenton formation." If one places the dividing line with Ulrich and Bassler, between divisions I and H, it probably falls in the covered interval. The upper beds of M contain *Camarotœchia plena,* the zone fossil of the Upper Chazy of Lake Champlain, together with *Camarella varians,* another typical Upper Chazy species. The same species are found in the lower part of N, which succeeds it; but the remainder of N, as well as divisions O and P, are, in part at least, a repetition of the series, including probably both the lower and the upper succession. If we include the series from D to the middle of Division M in the Beekmantown, we have a total of 2,615 feet for this formation and at least 560 feet for the succeeding Chazy. Judged by these standards, the North Scottish species listed under numbers 16, 17, 18, 19, and 26, and referred to the Chazy, would still be referable to the Beekmantown, thus increasing the Beekmantown species to 34, or about 56.5 per cent, while the Black River-Trenton forms comprise only 9 species, or 15 per cent. These, if correctly identified, would then have to be considered long-lived species.

Biri Limestone of Norway

In the Mjösensee district of Norway the strata which have been found resting on the crystalline basement complex have been divided as follows, in descending order, according to Goldschmidt.[9]

[9] Münster: Norg. Geol. Und. Aarbog for 1891 and Blatt Lillehammer, 1900. Goldschmidt: Ibid., 1908, vol. ii, p. 38.

Olenellus shale.
Upper Algonkian.
  Sandstone with tracks and trails.
  Quartz sandstone.
  Red and green shale.
  Younger sparagmite.
Middle Algonkian.
  Biri limestone.
Lower Algonkian
  Biri conglomerate.
  Red shale and limestone.
  Older sparagmite with dark shales.
Crystalline basement.

Between the Biri limestone and the succeeding beds there was postulated a marked hiatus, the higher beds resting unconformably on the folded and eroded Biri limestone and older beds.

In 1910 Prof. A. Rothpletz made a detailed study of these beds in the Mjösen region and came to the conclusion that the "Upper Algonkian series" represents merely the overthrust portion of the lower Sparagmite series which grades laterally into sands and quartzites. The series thus resolves itself into a basal sandstone, which merges laterally into Sparagmite and is followed by the Biri limestone. Such overthrusts from the north or northwest are frequent in the Scandinavian region, bringing sometimes the older sediments as well as the crystallines to rest on the Ordovicic and Siluric. Törnebohm has determined that the entire mass involved in the strata of the Mjösen district has been shoved some 130 kilometers or more eastward and southeastward from its original locality.

The Sparagmite comprises a mixture of arkoses with fresh feldspar crystals, and breccias formed of irregular fragments of crystalline rocks mostly with ill-defined stratification, but interbedded with well stratified sands and clays. Walther[10] has compared it with the Torridon sandstone of Scotland and considers both of torrential origin formed under the control of a semi-arid climate. The rock is the product of disintegration of the old basement crystallines and of the recomposition of this material into the Sparagmite, with but a small amount of sorting of the fragments. This basal Sparagmite and sandstone Rothpletz regards as, in part at least, early Cambric, though it may go back to pre-Cambric time. The Biri limestone, which succeeds it, is also considered by Rothpletz as of

[10] Über Algonkische Sedimente, von Johannes Walther. Zeitschrift d. deutschen geologischen Gesellschaft, Bd. 61, 1908, pp. 283-305.

Cambric rather than Algonkian age. No fossils have been found in this rock so far, so that its age is problematical. But if Rothpletz has solved the tectonics of the region correctly, it is most certainly Lower Paleozoic. The Biri limestone is a mixture of calcilutites and calcarenites; it is generally well stratified, and edgewise conglomerates, intraformational folding through slumping, as well as sun-cracks, appear in it, indicating relatively shallow water conditions during accumulation, with intermittent emergences. Ripple-marks were also observed by Walther on some of the surfaces.

The development of early Paleozoic rocks in a calcareous facies like that of the Biri limestone in the northwestern part of the Scandinavian land-mass, whence these thrust masses are derived, is the more remarkable, since the sandy and shaly development of these strata in the southern part of the peninsula and even in the region in which these limestones are now found shows a distinctly northward overlap, a condition of occurrence which presupposes the existence of a land-mass in the neighborhood. This land-mass must have lain between the area of the marine transgression from the south and the region of deposition of the Biri limestone. This limestone might be regarded as deposited in a great area of inland waters, but, as Walther rightly remarks, its extent and the absence of silicious clastics in it form a difficult problem on the basis of such an assumption. To be sure, the maximum thickness today is only 170 to 200 meters, but that is not its greatest original thickness, for its relation to the higher beds is in nowise definitely ascertained.

A more rational explanation of the origin of this limestone would seem to be that its accumulation took place in the waters of a sea lying to the north of the Scandinavian land-mass, formed at a time when the Atlantic Ocean transgressed across part of the same mass from the south. This would give these limestones and the underlying sandstones the same relationship to the Cambro-Ordovicic sandstones and shales in southern Sweden that the Eriboll quartzite and Durness limestone series have to the Lower Cambric sands and to the Tremadoc and Arenig beds of the south of Britain. On this basis, the Biri limestone would have to be considered the eastward continuation of the Durness limestone, just as the Cambric and early Ordovicic beds of Sweden are the eastward continuation of the sands and shales of Wales and England formed during the same period. Whether the Biri limestone represents only the Lower Cambric portion of the Durness—that is, the Ghrudaidh and Eilean Dubh groups—or whether a part of the Beekmantown facies is also included, must remain an unsolved question until fossils are discovered. Certainly there is nothing in the physical character of the Biri limestone which

differentiates it markedly from the early portion of the Durness limestone series, and, if the correlation here suggested be correct, we may confidently expect the finding at some future time of the true Olenellus fauna along the contact of the arenaceous and siliceous beds, and probably in the lower beds of the limestone as well, where Salterella and Hyolithes should occur. Nor is it impossible that some future favorable exposures of the higher parts of the limestone will reveal the presence in it of a scattered Beekmantown fauna such as has been obtained from the Durness limestone.

The alternative correlation favored by Rothpletz is that the limestones represent a local calcareous accumulation during Cambric time, while the darker muds of Sweden were deposited farther east, both, however, belonging to the same province. Such an interpretation presents some formidable difficulties, not the least of which is the determination of the source of the material in a region characterized everywhere else by mud deposition. One might, perhaps, refer the deposit to a supermarine origin, either in a playa lake or a river floodplain. But while this would explain the peculiar characters of the deposit and its lack of organic remains, it does not solve the mystery of the origin of the calcareous sediment. nor of the absence of clastic siliceous material in it.

Lower Ordovicic of the Atlantic Region

TREMADOC

The Lower Ordovicic of Britain begins with the Tremadoc series. This is a purely clastic series of terrigenous origin, typically seen in Carnarvonshire, North Wales, and extending into Merionethshire. It consists mainly of dark gray shales, which have a total thickness of about 1,000 feet and carry an abundant fauna. Two divisions are recognizable—a lower, with *Dictyonema socialis* (*D. flabelliforme*), and an upper, with *Asaphellus homfrayi*. Besides the Dictyonema, the lower division carries a trilobite fauna, in which *Niobe homfrayi, N. menapiensis, Psilocephalus innolatus, Angelina sedgwicki,* and *Asaphellus affinis* predominate. These shales are also found in the Malvern Hills, where they are 1,300 feet thick (Bronsil gray shales), but include about 300 feet of diabases and basalts. Since these beds carry the Dictyonema fauna throughout, they are believed to represent the Lower Tremadoc only.

In the Lake District of North England the Tremadoc rocks are included in the great shale series forming Skiddaw Mountain, as shown by the occurrence of Bryograptus in a part of this series. In Scotland these strata appear not to be developed, and we may infer that an old Ordovicic

land-mass—*Caledonia*—limited the English Sea, or more properly Channel, on the north. On the south, in Normandy and Brittany, these beds are likewise wanting, for here the Grès Armoricain, the chief representative of the Arenig, either rests directly on the crystallines or is preceded by red shales of continental origin, which range up to 2,500 meters in thickness, and generally follow on a basal grit and conglomerate, the thickness of which may reach 500 meters or more. A part of this series probably represents continental Cambric, but some of the red shales, marked by Scolithus, *Tigillites linearis,* and *Vexillum desglandei,* may represent Lower Arenig or Tremadoc.

This southern region of continental deposition constituted the old land-mass of *Armorica* and separated the Ordovicic English Channel from the Mediterranean Basin. For on its southern border, near Cannes and Saint Chinian, in Montagne Noire, we find the Cambric succeeded by beds of Tremadoc age, carrying, however, a series of fossils distinct from those found in the northern area and described and named by Munier-Chalmas and J. Bergeron. These are: *Euloma filacovi, Agnostus ferralsensis, Megalaspis filacovi, Asaphelina barroisi, Dictyocephalites villebruni, Dicellocephalus ? villebruni,* and *Bellerophon oehlerti.* These beds are followed by blue shales with *Asaphelina miqueli* J. Berg., *Niobe lignieresi* J. Berg., and these by black shales with *Amphion escoti* J. Berg. and other fossils. These are succeeded by the Tetragraptus shales. In Spain, near Barcelona, the Tremadoc is likewise represented by shales carrying *Ogygia* cf. *desiderata* Barr., *Asaphellus* cf. *solvensis* Hicks, *Asaph. innotatus* Barr., *Asaph.* cf. *wirthi* Barr., *Niobe* cf. *homfrayi* Salter, etcetera. Elsewhere, however, this horizon seems to be overlapped by the Arenig (Grès Armoricain).[11]

ARENIG

General discussion.—Above the Tremadoc follow the Arenig shales and grits with apparent conformity and with a maximum thickness of 2,000 feet. This series, besides containing a number of brachiopods (Lingula, Orthis, etcetera) and trilobites (Æglina, Barrandia, Calymene, Illænus, Trinucleus, Placoparia, etcetera), is especially characterized by graptolites. The series is separable into a lower or Tetragraptus zone, containing *T. serra* (= *bryonoides*), *T. quadribrachiatus, Didymograptus extensus, D. pennatulus,* and the genera Retiograptus, Loganograptus, Clonograptus, Schizograptus, and Dichograptus, mostly types characteristic of our Lower Deepkill shales of the Hudson Valley. The Upper Arenig is characterized by *Didymograptus bifidus, D. patulus, Climaco-*

[11] A. Douvillé: Handb. Reg. Geol., Bd. iii, 3, Heft 7.

graptus conferta, and *Diplograptus dentatus.* The first of this series is diagnostic of our Middle and the last of our Upper Deepkill zone, the Deepkill on the whole being thus equivalent to the Arenig.

While in the Hudson Valley the Upper Deepkill beds appear to be succeeded disconformably by the Normanskill beds of Upper Chazy or Black River age, the Arenig of Wales seems to be conformably succeeded by the Llandeilo. No positive evidence is at present available to show whether there is or is not a hiatus between these two formations in Britain, but I am inclined to think that careful search will reveal its existence in some sections. In South Wales the Llandeilo has a thickness of 2,000 feet and is divisible into the following members:

	Feet
Upper Llandeilo slates	1,000
Llandeilo limestone	200
Lower Llandeilo slates	800

The lowest zone of the Llandeilan is characterized by *Didymograptus murchisoni,* the Middle by *Diplograptus foliaceus* and *Climacograptus scharenbergi,* and the Upper by *Cryptograptus tricornis, Climacograptus scharenbergi, Cœnograptus* (*Nemagraptus*) *gracilis,* and *Dicellograptus sextans.* This association of species in the Upper Llandeilo is also characteristic of the Normanskill beds of New York, which thus appear to represent the exact equivalent of the Upper Llandeilo. Characteristic Lower Llandeilo trilobites are *Asaphus tyrannus, Calymene cambrensis, Trinucleus lloydii,* and *T. favus,* while those of the Upper Llandeilo include *Barrandia cordai, Cheirurus sedgwicki,* and *Ogygia buchii.*

Scotland.—In the southern uplands of Scotland both Arenig and Llandeilo rocks are present. The former are represented by radiolarian cherts and by mudstones of unknown thickness. They appear to overlap the Tremadoc and probably represent only a part of the Arenig series. In Dumfriesshire they are complicated by volcanic flows, which also overlie and separate them from the Llandeilo. There seems to be a disconformity in this region between the Arenig and the overlying Glenkiln shales, which carry a Normanskill or Upper Llandeilo fauna.

The disconformity and hiatus is well marked in the Girvan district of southwest Scotland (Ayrshire), where the Lower Llandeilo is overlapped by the Upper, which rests with a basal conglomerate on the Arenig cherts.

The Arenig or Ballantrae series contain:[12]

Phyllograptus typus Hall
Tetragraptus quadribrachiatus Hall

[12] Charles Lapworth: On the Ballantrae rocks of south Scotland and their place in the Upland Sequence. Geological Magazine, n. s., Dec. 3, vol. vi, 1889, pp. 20-27 (22).

T. bryonoides Hall (*T. serra*)
T. fruticosus Hall
T. bigsbyi Hall
Didymograptus extensus Hall
D. bifidus Hall
Caryocaris wrightii Salter
Dictyonema, Lingula, and Obolella.

D. bifidus is an Upper Arenig type, but it is probable that this series of rocks is Lower Arenig, as indicated by the other species.

The Llandeilo is here represented by the *Barr Series*, which comprises the following members, in descending order:

7. Benan conglomerate	1,000 feet plus
Stinchar calcareous group:	
6. Green mudstones and shales with	
1. *Didymograptus supertis* Lapw.	
2. *Dicellograptus sextans* Hall	
3. *Clathrograptus cuneiformis* Lapw.	
4. *Glossograptus hicksii* Hopk.	
5. *Cryptograptus tricornis* Carr.	
6. *Diplograptus rugosus* Emm.	30 feet
5. Compact limestone with few fossils, including Saccamina and Girvanella.	
4. Nodular, flaggy Maclurea limestone and shales with *Maclurea logani, Tetradium peachi,* etcetera. Thickness of 5 and 4 about	70 feet
3. *Orthis confinis beds*, flaggy, impure, calcareous, with *O. confinis* Salter, *O. alternata* (Salter), *Strophomena grandis* (Salter). Thickness	60 feet
Kirkland group:	
2. Purple sandstones and grits, with occasional *Orthis confinis* and *Strophomena*	40 feet
1. Purple conglomerate	150 feet plus

The conglomerate rests on the eroded surface of the Lower Arenig and consists of worn fragments of these rocks and the volcanics associated with them. It contains pebbles of chert, black shale, lavas, and tuffs, "together with serpentine, gabbro, dolomite, and even granite."[13] The calcareous beds make correlation with other horizons possible. The flags with *Orthis confinis* also contain *O. calligramma* (Dalm.) in some sections, together with *O. flabellulum* (Sow.) and *Strophomena expansa* (Sow.). The first of these is wide-spread, occurring in the Baltic provinces of Russia in horizon B III and C (see postea). *O. flabellulum* is

[13] Peach and Horne: Loc. cit., p. 484.

found in the Lower Lykholm beds of Esthonia, which, according to Bassler, correlate with our Lower Trenton. *Strophomena expansa* occurs even higher than this, being found in Esthonia in the Borkholm limestone, which is regarded as late Ordovicic. *Maclurea* (*Maclurites*) *logani* Salter is found in North America in the Black River beds of Allumette Island, Ottawa River (Leroy horizon) and the Mingan Islands, Canada, and also in Bessels Bay, Arctic America. It appears thus to belong to the fauna entering North America from the Atlantic. *Tetradium peachi* Nich. and Eth. is now referred to *Solenopora compacta* (Billings), a form widely distributed in the Middle and Upper Ordovicic, especially in the Black River and Trenton of eastern North America. *Nidulites favus* (Salter), which also occurs in this limestone, has been obtained from similar beds in Quebec. The graptolites of formation 6 are mostly typical of the American Normanskill fauna, all but number 4 having been recorded from this country.

According to this standard, then, our Normanskill fauna should lie *above* the Black River fauna and represent essentially early Trenton—a conclusion reached likewise by Ruedemann.

The Benan conglomerate (7) rests disconformably on the Stinchar group, cutting across the graptolite shales on which it rests at Benan Burn, until at Auchlewan Burn it rests on the eroded surface of the Stinchar limestone (No. 5). This descent across the graptolite shales occurs within a distance of 200 yards. The conglomerate in places is almost destitute of bedding planes, except by the arrangement of pebbles into lines in some cases. It furthermore contains fragments of the limestone.

The matrix of the conglomerate is derived from the disintegration of the basic igneous rocks of the region. The pebbles, often of the size of boulders and generally well rounded, are derived from the Arenig volcanic plateau. The disconformity does not necessarily mark a hiatus of great extent, since the conglomerate is a continental deposit which was spread out over the marine series, the terrestrial sediments pushing back the seashore as they advanced. This conglomerate marks the inpouring of a mass of coarse river sediment at this place from the highland lying to the northwest, which had been elevated, and it corresponds essentially to the conglomeratic deposits built into the retreating Ordovicic sea in North America, but derived from the Appalachian land on the southeast. The formation of the American representative, however, the Bald Eagle conglomerate, began somewhat later than the Benan, which is regarded as closing the Llandeilan stage, while the Bald Eagle is post-Trenton. That the region was again submerged in Caradocian time is shown by

the presence above the Benan conglomerate of the extensive series of Caradocian sediments with marine fossils, whereas in America emergence continued during the equivalent Upper Trentonian time.[14] The Benan conglomerate overlaps the earlier Llandeilo beds southward, where it comes to rest directly on the disturbed and eroded surfaces of the Arenig volcanics.

Lake District.—It is possible that the whole of the Arenig is represented in the great series of Skiddaw shales in the Lake District, and some Llandeilo may even be included in the upper part of the series. Most of Llandeilo time, however, was occupied by the eruption of the great Borrowdale volcanic series, which continued into Caradocian time, for late Caradocian strata alone succeed this series. This region was thus probably land during the whole of Middle Ordovicic time, as there is no reason to assume that the eruptions were of a submarine character.

Wales.—In the Welsh region, on the other hand, deposition seems to have been continuous from Arenig into Llandeilo time, as indicated by the transitional facies for which Hicks has coined the term *Llanvirn* series. This comprises some 2,000 feet of shale near Saint Davids.[15]

Normandy and Brittany.—Turning now again to the southern border of the English Lower Ordovicic sea, we find the Arenig represented in Normandy and Brittany by the Armorican grit (Grès Armoricain), a formation consisting mostly of white quartzite and ranging in thickness up to 500 meters in Brittany,[16] and well exposed along the coast of the Crozon Peninsula between the Rade de Brest and the Baie de Douarnenez. The beds of this region are thrown into a series of isoclinal folds which have a steep dip to the north, the southern limbs of the folds being overturned and the whole complicated by faults and by diabase dikes and other intrusives.

The general strike is east-west, though pronounced local variations occur. In this section the Armorican grit rests with a disconformity on the Upper Cambric Lingula sandstones (schistes pourprés), which in turn rest on the Paradoxides beds, and these are disconformably preceded by the Brioverien series of phyllites, sandstones, conglomerates, and calcareous beds (also called the Phyllades de Saint Lô), the oldest sedimentaries of Brittany and regarded as of pre-Cambric age. The Ordovicic series begins with the Erquy pudding-stone, a coarse conglomerate composed of fragments of the sediments and eruptives of the Cambric. This is followed by a coarse-grained, feldspathic, non-fossiliferous grit,

[14] A. W. Grabau: Early Paleozoic delta deposits. Bull. Geol. Soc. Am., vol. 24, pp. 399-528.

[15] Hicks: Pop. Science Review, 1881, p. 289.

[16] Ch. Barrois: Guide de Bretagne, p. 10.

which has been regarded as representative of the Tremadoc, and is, in any case, a continental formation. Above this lies the Armorican grit proper or the "grès du Toulinquet" with intercalated shaly beds. This series contains fossiliferous members, some of them truly marine and others of shore or possibly supra-marine types. Among the latter are numerous trails and other markings generally preserved in relief, such as *Tigillites dufrenoyi, Cruziana furcifera, C. prevosti, C. bagnolensis, Vexillum* sp., *Dædalus, Lumbricaria,* etcetera, while the former include many species of *Lingula* (*L. lesueri, L. salteri, L. hawkei,*[17] etcetera) and *Dinobolus bimonti.* It further contains the pelecypods *Lyrodesma armoricana, Modiolopsis caillandi, Ctenodonta costæ, Nuculana incola,* and *Actinodonta cuneata,* while the trilobites are represented by *Ogygia armoricana.* The horizon here indicated is probably Lower or early Middle Arenig. The Armorican sandstone is disconformably succeeded by the "Schistes d'Angers." These comprise, accordang to Kerforné, the following divisions, in descending order:

6. RAGUENEZ SHALES. Black shales with *Acaste proæva* and *Synhomalonotus arago* (a fauna originally described from Spain by Verneuil and Barrande).
5. KERARMOR SHALES. Black shales with *Trinucleus bureaui.*
4. MORGAT SHALES with *Placoparia tourneminei, Asaphus glabratus, Acaste phillipsi* (a fauna originally described by Sharpe from Portugal).
3. KERARVAIL SANDSTONE.
2. SION SHALES with *Synhomalonotus tristani, Asaphus guettardi, Calyx murchisoni.* This is also the horizon of *Didymograptus geminiformis.*
1. BED OF OOLITIC IRON ORE.

Disconformity.

ARMORICAN GRIT.

The fauna of these shales suggests early or Middle Llandeilo, corresponding approximately to Dd γ of the Bohemian series. The Angers shales are succeeded by the *Saint Germain sur Ille sandstone,* which Barrois correlates with the Glenkiln beds of Scotland. It is a shaly micaceous sandstone containing Diplograptidæ, *Synhomalonotus arago, Acaste incerta,* and *Trinucleus.* The highest Ordovicic division of Brittany is the Rosan limestone with a Caradoc fauna, including *Orthis actoniæ, Triplesia spiriferoides,* and *Trinucleus.*

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[17] This species is reported by Van Ingen from oolitic hematite at the top of his Bell Island Series, at a horizon which he places between the Middle and Lower Arenig.

In Normandy the Cambric, when present, rests with an unconformity on the folded and eroded "phyllades de Saint Lô" of Algonkic age. In the province of Orne the Grès Armoricain rests disconformably on the Cambric, but in the southern part of the adjoining province of Manche it rests unconformably on the Saint Lô phyllites, the Cambric, if deposited here, evidently having been eroded before the deposition of the Armorican sandstone. Moreover, the Armorican sandstone has a transgressive character and varies in thickness from 12 to a maximum of 500 meters. It is followed disconformably by the Angers roofing slates (Schistes à Calymène), with a thickness of 30 meters or less, which contain in their basal part *Didymograptus geminus* and *Calymene aragoi,* and *Calymene tristani* and *Trinucleus bureaui* in the upper part. Other species are: *Dalmanites phillipsi, Uralichas ribeirei, Asaphus guettardi, Illænus giganteus, Placoparia tourneminei, Cheirurus andegarus,* ostracods, cephalopods, pelecypods, and brachiopods, including *Orthis budleighensis.* Near Caen (Calvados) the Angers slates are succeeded by the May sandstone (grès de May), which still contains in its lower part *Calymene tristani* and is otherwise rich in trilobites.

In the valley of the Mayenne the pre-Cambric beds are succeeded, apparently with a disconformity, by the Gourin pudding-stone, and this by the Armorican sandstone, the Cambric being absent here. That the Cambric formerly extended over much of this region is shown by its presence in the basin of Laval, which lies between this region and southern Manche (Mortain), where the Cambric is likewise absent, though to the east in Orne it is again present. From this we may conclude that the epoch of the Armorican grit was preceded by one of erosion, which removed the Cambric formations from parts of this region. This is also shown by the conglomeratic character of the base of the Armorican, where it rests on the Cambric (see in Brittany). The Armorican sandstone and the succeeding Angers slates with *Calymene tristani* are here much thinner, the hiatus between them being greater than farther north. At Montigné, on the southern flanks of the Laval basin, the Armorican sandstone is reduced to a few thin, sandy beds with *Lingula lesueuri.* This rests without the basal conglomerate on the pre-Cambric beds, apparently with a disconformity, and is succeeded by the Angers series, somewhat slaty, very black, and poor in fossils. This is followed by the Saint Germain-sur Ille sandstone with *Orthis berthoisi* var. *erratica.*

These sections thus indicate a transgression of the sea from the north over the old Armorican land-mass which included the central area of France. After the deposition of the Armorican sandstone, the sea again withdrew, to return in mid-Ordovicic time, when the Angers argillulites

(now slates) were deposited. The hiatus between the Armorican sandstone and Angers mudstones corresponds to the hiatus between the Lower Arenig and the Glenkiln of Scotland, and this indicates that the retreat of the sea at the end of Arenig time resulted in a narrowing of the English Channel. Whether the British area emerged completely, so that a continuous land-mass extended from the old land of Scotland (Caledonia) to France (Armorica) must be determined by a further study of the Welsh sections. If these, too, show a hiatus between the Arenig and Llandeilo, such complete withdrawal of the sea would be indicated. The fact that in South Wales the Upper Arenig and Lower Llandeilo form apparently a unit, the Llanvirn group of Hicks, 2,000 feet thick, near Saint Davids, indicates that here at any rate deposition was continuous. This does not argue, however, for continuity to the east of this, for there dry land probably existed, as is indicated by the conditions in the Baltic region, to be discussed subsequently in this paper. The southern Wales district may have constituted an embayment from the Atlantic Ocean of Llanvirn time.

Mediterranean Region

IBERIAN PENINSULA

On the southern border of the ancient Armorican land-mass, or the Iberian Peninsula of early Ordovicic time, the Tremadoc beds, as already noted, are found at Montaigne Noire in southern France and at Barcelona in Spain; but inland (northward and westward) they are overlapped by the transgressing Arenig, here also represented by rocks of the Armorican sandstone type. Much, if not all, of the southern part of the peninsula (Spain and Portugal) seems to have been covered by the Arenigian during its greatest advance; but central France probably remained above water. With the succeeding retreat of the sea, however, the whole of this region seems to have been uncovered again, for even at Barcelona the Armorican sandstone is only slightly developed, having probably been in part removed by erosion during the retreat. More evident, however, of the presence of a hiatus between it and the succeeding beds is the fact that it is followed by beds with *Orthis actoniæ* Sow., *O. vespertilio* Sow., *O. calligramma* Dalm., *O.* (*Dalmanites*) *testudinaria* Dalm., *Plectambonites sericeus* Sow., *Echinophærites* cf. *balticus*, etcetera, these clearly proving Caradoc age for these beds. Thus the Llandeilo is absent altogether, being overlapped by the Caradoc, which probably represents a continuation of the transgressive movement begun in Llandeilan time. Speaking in terms of the American series, beds of early Beekmantown age are here followed by Middle Trenton, a condition not infrequently

found in some American sections, and due to the same eustatic movement.

In the Iberian chain of the ancient province of Aragon the Armorican sandstone is only about 30 meters thick and rests on a ferruginous upper member of the Cambric, the hiatus between the two being somewhat marked. This is followed by the Angers slates, 25 to 30 meters thick, and characterized by *Calymene tristani* Bron., *Orthis budleighensis* Dav., *Redonia,* etcetera. A 12-meter bed of unfossiliferous quartzites separates this from shales with *Orthis actoniæ* Sow., *O. alternata* Sow., *Orthis budleighensis* Dav. This is probably the Ashgill horizon. Beds of this age with *Orthis actoniæ, O.* cf. *vespertilio, Strophomena expansa, Tentaculites, Chætetes, Favosites,* and *Strophostylus* form the oldest fossiliferous horizon of the Pyrenees.

In the Sierra Morena and the mountains south of Toledo beds of the age of the Angers slates and the May sandstone (Llandeilo) are known, resting on a thin quartzite with Cruziana, which may represent a part of the Armorican grit. The Arenig series seems to be largely wanting here, either through non-deposition or on account of erosion during the retreatal interval.

The fossils found in the Ordovicic beds of this southern half of Spain are all from the beds belonging to the higher or retransgressive series. These include:

Placoparia tourneminei M. Rouault.
Cheirurus marianus de Vern.
Homalonotus rarus Corda.
H. brongniarti Desl.
Calymene pulhra Barr.
C. (*Synhomalonotus*) *tristani* Brong.
C. aragoi M. Rouault.
C. tristani de Vern. et Barr.
Dalmanites socialis Barr.
D. downingiæ Murch.
D. vetillarti M. Rouault.
D. torrubiæ de Vern. et Barr.
D. phillipsi Barr.
D. dujardini M. Rouault.
Lichas hispanica de Vern. et Barr.
Trinucleus goldfussi Barr.
Asaphus nobilis Barr.
A. cianus de Vern. et Barr.
Asaphus contractus de Vern. et Barr.
A. glabratus Sharpe.
Illænus hispanicus de Vern. et Barr.
Ill. sanchezi de Vern. et Barr.

The close relation of these faunas to those of the Bohemian series D 2 to D 4 is apparent, while at the same time its distinctness from that of the Baltic region is seen.

The Ordovicic beds of northwest Spain, in the provinces of Galicia and Asturia, belong to the series of deposits formed on the northwestern flanks of the Armorican land-mass, in continuation of those of Brittany. In both regions the Cambric begins with the Rivadeo series, consisting of about 3,000 meters of green, greenish, or bluish shales and quartzites, and resting on the pre-Cambric, which in some sections are said to pass upward into the Cambric beds. This is followed by the Vega series, beginning with a bed of iron ore 1 to 2 meters thick, followed by a limestone 20 to 60 meters in thickness, and then by fossiliferous greenish shales and quartzites from 50 to 100 meters thick. This latter series carries the Paradoxides fauna. Above this follows the Cabo Busto sandstone, which generally begins with a pudding-stone, and reaches the great thickness of 1,500 meters in Galicia. It contains Scolithes and Cruziana (Bilobites) and represents the basal Ordovicic, which thus rests disconformably on Middle Cambric. The formation is mostly continental in origin, though in Asturia some of the lower beds contain *Lingulella heberti*. The Cabo Busto sandstone is also terminated by a thin bed of iron ore, above which lie the Luarea shales, the essential equivalent of the Upper Angers slates. These are 100 meters thick at Cap Vidrias and contain *Calymene* (*Synhomalonotus*) *tristani*, *Asaphus glabratus, Dalmanites phillipsi, Bellerophon bilobatus, Redonia, Echinosphærites murchisoni,* etcetera. This corresponds approximately to the Sion shales of Brittany and in a general way to the early Trenton of North America.

MONTAGNE NOIRE, SOUTHERN FRANCE

We have already seen that representatives of the Tremadoc are found here, lying on the Cambric, probably with a disconformity. "They pass upward into the *Boutoury shales* with Tetragraptus, Didymograptus, and *Rouvillograptus richardsoni* Barr., as well as trilobites. These represent the early Deepkill beds of America, and they are succeeded by sandstones with *Vexillum, Cruziana, Lingula lesueuri* Rou., and other species, and occasionally *Dinobolus brimonti* Rou. This represents the Armorican sandstone of northern France and Spain. It is extremely unlikely that the Armorican sandstone extended entirely across France. The old Armorican land-mass probably remained intact through Arenig time, and the migration of the fauna into the Mediterranean region was around the southern end of the peninsula.

BOHEMIA

In portions of the Bohemian basin the Middle Cambric Skrej Jinetz formation of Bohemia is followed with a marked disconformity by the sandstones of the Krŭsnáhora formation (D 1 α), which are characterized by *Lingula feistmanteli.* These beds have often been placed in the Upper Cambric, but they are more properly classed as basal Ordovicic. Marr considers that *L. feistmanteli* "is very near to the remarkable *Lingula roualti* of the Armoricain grit."[18] He concludes that these beds are therefore late Arenig, the Lower Arenig and Tremadoc being absent in Bohemia.

The Krŭsnáhora beds are quartzites, often glauconitic graywackes, shales, and hornstones. These Krŭsnáhora beds are absent throughout the Jince district of the Bohemian basin, where the Paradoxides beds are either followed by the ironstone-bearing zone of d 1 β or by d 2.[19] The Lower Ordovicic division, which is most wide-spread in Bohemia, is the Komorau formation or d 1 β of Barrande. This consists of black shales, hematite ironstones, diabase, and diabase tuffs, the total not exceeding 100 meters. It often overlaps the Krŭsnáhora beds, resting directly on the Middle Cambric. The fossils found in this formation include:

Orthis desiderata Barr.,
Lingula,
Harpides grimini,
Amphion (*Pliomera*) *lindaueri*, and
Didymograptus (*Isograptus*) *caduceus* (Salter).

The graptolite indicates Lower Deepkill for this series, and this is not negatived by the other species. Marr would refer this division "to a position high up in the Arenig series." Here he would also place the next succeeding Kván-oseker beds d 1 γ of Barrande, dark, mostly black clay shales, and graywackes, with sandy intercalations. They contain:

Placoparia zippei,
Ogygia,
Asaphus nobilis,
Illænus katzeri,
Bohemella,
Dalmanites,
Niobe discreta,
Æglina prisca,
Rhiveiria,
Orthis, and
Didymograptus geminus.

The graptolite marks this horizon as of Lower Llandeilo age, the hiatus between it and the preceding Komorau formation (d 1 β) including at least Middle and Upper Arenig. These mid-Ordovicic beds are succeeded

[18] Geol. Mag., Sept., 1889, decade iii, vol. vi, p. 413.

[19] Jaroslav J. Jahn: Geologische Exkursion im Älteren Palæozoikum Mittelböhmens. Führ. Cong. Geol. Int., IXe session, pp. 42-45; footnote.

by Barrande's Division D_2, the Dráboyer beds, consisting of quartzites, quartzitic sandstones, and clay shales. The series appears to be conformable with the Kván-oseker beds, some of the species of the latter continuing upward into the Dráboyer beds. This horizon is characterized by *Dalmanitina socialis* Barr., *Trinucleus goldfussi* (which continues upward into D 3), *Asaphus nobilis, Homalonotus,* etcetera.

These beds represent the Upper Llandeilo horizon. Above them follows with apparent conformity the Trubiner black shales, with occasional intercalations of thin beds of grit (D_3), and the Zahorauer grits and shales (D_4). Both these formations contain *Trinucleus concentricus* (*T. ornatus*) and represent approximately the horizon of the American Trenton and the British Caradoc. Overlying this are the Königshofer shales and Kosover quartzites with *Trinucleus seticornis,* etcetera, which constitute the highest Ordovicic, and are followed disconformably by the Siluric.

The Bohemian series extends into the adjoining region of Bavaria, where, near Hof, the Cambric shales are followed disconformably by the Leinitz shales carrying *Orthis* cf. *desiderata* Barr. and corresponding to the Bohemian D *d* 1 *β*. Higher Ordovicic beds are not represented there by fossiliferous strata.

Lower Ordovicic of the Baltic Region

THE ORTHOCERAS LIMESTONE

This name is in general use in the Scandinavian region for a limestone series included within the graptolite-bearing shales of the Ordovicic. The name is applied in different sections to limestones not always covering the same geological interval, since some of the subdivisions found in one section may be wanting in another, or may there be replaced by graptolite-bearing shales. In the province of Esthonia, on the German-Russian side of the Baltic, similar limestones are developed, though they are perhaps less frequently known by the name of Orthoceras limestone. I have had an opportunity to study these rocks under the guidance of several Swedish geologists in the provinces of Westergotland, Dalarne, and Scania, and have had occasion to consult the recent literature on these as well as the Norwegian and the Esthonian regions.

A typical section of this formation is furnished by the classical exposures in the hill known as the Kinnekulle on the southeastern side of Lake Venern, near Rabäck station. This hill and its rich yield of Paleozoic organic remains was first made known by the work of Kalm in 1742 and of Linnæus in 1747, and has since been the object of study of many an eminent investigator, both native and foreign. Angelin in 1852 made

the first paleontological subdivision of the strata of this region, and on this is based practically all of the subsequent work. But it was Gustav Linnarsson, a native of Westergotland, who, in 1869, in his work, "Om Vestergötlands Cambriska och Siluriska aflagringar," placed the knowledge of the geological succession of this province on a modern basis, and so laid the foundation for subsequent study of the Paleozoics of Sweden.[20]

Extensive studies of this section were made by G. Nathorst, 1881; G. Holm and H. Munthe, 1901, and by Munthe, 1906; by Wiman, 1910, and by others.

The entire section of the Kinnekulle is as follows, in descending order, chiefly after Wiman, with observations of my own added:

Diabase (intrusive) forming the top of the hill .... 30 m.+

Siluric (Upper Llandovery).

Upper Graptolite shales, 56 m., divisible into—

b. *Retiolites shales* with *Retiolites geinitzianus* Barr., *Monograptus crenulatus* Tqt., *M. priodon* Bronn, *M. culellus* Tqt., and *M. subconicus* Tqt.

a. *Rastrites shale* with *Rastrites hybridus* Lapw. and with *Monograptus runcinatus* Lapw., *Diplograptus* (*Cephalograptus*) *cometa* Gein., *D.* (*Petalograptus*) *folium* His., and *Monograptus triangulatus*, Harkn.

Hiatus.

Ordovicic.

Brachiopod shale, a calcareous shale passing upward into a sandstone and carrying *Dalmania mucronata* Brgn., *D. pulchella* Lns., and *Homalonotus platynotus* Dalm .... 2 m.

Trinucleus shale, comprising

Red Trinucleus shale with *Remopleurides radians* Barr., *Cybele verrucosa* Dalm., *Trinucleus wahlenbergi* Rault, *Ampyx tetragonus* A., *Dionide euglypha* A., *Agnostus trinodus* Salter, etcetera .... 18 m.

Limestone stratum .... 2 m.

Black and green Trinucleus shales .... 12 m.

Total Trinucleus shale .... 32 m.

Chasmops beds, dark shales with graptolites and numerous concretionary limestone masses and beds of impure limestone containing *Chasmops* sp. *Remopleurides sexilineatus* A., *Ptychopyge glabrata* A., *Ampyx rostratus* Sars., *A. costatus* Boeck., *Agnostus trinodus* Salter, *Beyrichia costata* Lns., *Primitia strangulata* Salt., and numerous *Echinosphærites aurantium* Gyllenh., especially in the lower part .... 10 m.

[20] K. Swenska: Vetenskaps Akademiens Handlingar, Bd. 8, No. 2, Stockholm, 1869.

Orthoceras limestone, comprising—

(*d*) *Upper gray* or Chiron limestone with *Illænus chiron* Hm., *Ogygia dilatata* Brünn var. *sarsi* A., *Ancistroceras undulatum* Boll., and *Discoceras teres* Eichw.. 10 m.

(*c*) *Upper Red*, including—

$(c)_2$ *Platyurus limestone* with *Asaphus platyurus A.* and *Orthoceras tortum* and

$(c)_1$ *Gigas limestone* with *Megalaspis gigas*.[21]

Total c_1 and c_2...................... 24 m.+

(*b*) *Lower gray* or *Asaphus limestone* with numerous fossils, including *Cyrtometopus clavifrons* Dalm., *Phacops sclerops* Dm., *Asaphus raniceps* var. *maxima* Br., *Megalaspis heros* Dm., *M. rotundatus* A., *M. explanata* A., *Illænus esmarki* Schloth, *Ampyx nasutus* Dm., *Endoceras wahlenbergi* Foord, *Orthoceras kinnekullense* Foord, *Estonioceras proteus* His., *Bathmoceras linnarssoni* A., *Gonionema bicarinatum* His., *Raphistoma gradatum* Koken, *Orthis* sp. and *Sphæronis pomum* Gyllenh., the latter in rock-forming quantity .... 6 m.

(*a*) *Lower red* or *Limbata limestone* with *Megalaspis limbata* S. & B. and *Nileus armadillo* Dm............. 12 m.

Total Orthoceras limestone.................. 52 m.+

Lower Didymograptus shale, light greenish gray shale with *Phyllograptus densus* Tqt., *Didymograptus extensus* Hall, *Tetragraptus quadribrachiatus* Hall, and *T. fruticosus* Hall.. 10 m.

Planilimbata limestone, gray limestone with *Megalaspis planilimbata*, *Eorthis christianæ*, etcetera...................... 0.5 m.

Ceratopyge limestone, upper part glauconitic limestone, with *Ceratopyge forficula* Sars., *Euloma ornatum* A., *Cyrtometopus primigeus* A., *Niobe insignis* Lns., *Symphysurus angustatus* Boeck, *Nileus limbata* Brögg, and *Eorthis christianiæ* (Kj.), *lower part* glauconitic shale with *Lycophoria lævis* Stolley... 2 m.

Total shales and limestones......................... 12.5 m.

Hiatus? with Dictyonema shales wanting—possibly replaced by Lower Ceratopyge limestone.

Cambric.

Upper Cambric alum shale containing in the upper beds *Peltura scarabioides* Wbg. and *Sphæropthalmus alatus* Boeck; a phosphate conglomerate with *Orthis lenticularis* and fetid limestone layers (1.6 meters thick), some beds of which are

[21] This species has not been reported from the Kinnekulle, but occurs elsewhere in Wester-Gotland.

entirely composed of *Agnostus pisiformis* L. and others largely of *Olenus gibbosus* Wbg. *A. pisiformis* also occurs in the lower shales..	15.6 m.
Middle Cambric Paradoxides beds—	
Not exposed at present..................................	6.4 m.
Lower Cambric, comprising	
Lingula sandstone with Lingula sp.......................	20. m.
Mickwitzia sandstone with	
Mickwitzia monilifera Lns. and *Torellella lævigata* Lns., together with impression of *Medusites lindströmi* Lns., *M. favosus* N., *M. radians* Lns., and the raised "trails" which have been referred to Cruziana—and the so-called *Eophyton*, from which this sandstone originally received its name of "Eophyton sandstone." The base is formed by a conglomerate containing "dreikanter" of quartz, of which several excellent specimens were obtained at Lugnås	10 m.
Total Cambric..................................	46 m.

Weathered gneiss, quarried for millstones.

In a small stream on the west side of the Kinnekulle near Trollmen, where the Lower Didymograptus shale was exposed with the Ceratopyge limestone below it, we found, in the upper beds of the latter, which here is a gray limestone, numerous pygidia of *Megalaspis planilimbata*, together with a few specimens of other trilobites and *Eorthis christianiæ*. This seems to indicate that this exposure is the *Planilimbata* limestone, which here appears to be continuous with the Ceratopyge limestone. To be sure, the entire mass of the limestone was not exposed, the exposures being rather a series of ledges in the small stream. This makes it possible to overlook any disconformity which might exist between the Ceratopyge and Planilimbata limestone, though certainly none such could be found after careful search. Moreover, these limestone beds evidently lay below the Lower Didymograptus shales, which were exposed farther up the hill, though no actual contact between the two series could be found; nor could a fault be assumed between the two exposures, for this would place the Ceratopyge limestone with the Planilimbata limestone *above* the Didymograptus shales. When it is remembered that the Ceratopyge beds are universally found at the base of the Ordovicic—equivalent in part to the Tremadoc of Britain and perhaps the Potsdam of North America—while the Lower Didymograptus shales are the equivalent of our *Lower* Deepkill zone, it is apparent that the Planilimbata limestone here exposed is of early Ordovicic age, the practical equivalent of our lowest Beekmantown, the Little Falls dolomite, or perhaps the Theresa or Hoyt lime-

stones, both of which form transition beds to the Lower Beekmantown or Little Falls dolomite.[22]

The great faunal difference between the West European early Ordovicic and that of eastern North America is probably to be explained by the difference in origin of the faunas, the Beekmantownian being primarily a Boreal[23] or northern fauna in the east and northeast and a South Pacific fauna in the south and west, while the West European limestone fauna is of North Pacific or of Siberian origin. The graptolite fauna, however, was undoubtedly, in part at least, existent in the Atlantic.

The close association of the Ceratopyge limestone and the limestone with *Megalaspis planilimbata* in the Trollmen region above noted, and the occurrence of the Lower Didymograptus shales above it, precludes the possibility of the existence of a pronounced hiatus (if any) between the Lower Red Orthoceras limestone (*Megalaspis limbata* limestone) and the Lower Didymograptus shale, because *M. planilimbata* and *M. limbata* are found associated in the same beds in regions where the Lower Didymograptus shale is wanting as in Dalarne, discussed further on. It would thus appear that the Lower Didymograptus shale, when present, replaces a part or all of the Planilimbata limestone and perhaps a part of the Limbata limestone as well. Farther east, in Westergotland, at Œdegarden, the Lower Didymograptus shale is wholly replaced by the *Megalaspis planilimbata* limestone, which, as we were able to judge under the expert guidance of Professor Wiman, is here intimately associated with the Ceratopyge limestone, which in turn rests disconformably on the Upper Cambric Stinkkalk with Peltura and Sphæropthalmus.

[22] I am well aware that Ulrich separates the Little Falls dolomite from the Beekmantown and refers it to his Ozarkian. I have not yet seen any evidence which makes the separation of the Ozarkian as a distinct system permissible. The Little Falls dolomite, in my view, represents the transgressive portion of the early Ordovicic (Beekmantownian of my classification) which culminated with the deposition of the Tribes Hill limestones, which I consider as essentially continuous with the Little Falls dolomite. During the early regressive phase of the Beekmantownian, beds similar to the Little Falls in lithic character were probably deposited above the Tribes Hill in the Mohawk Valley, but these were eroded during the long interval of exposure between the retreat of the sea in early Beekmantown and its return to the Mohawk region in late Chazyan time (Lowville). During this interval the Tribes Hill was also removed by erosion in the eastern portion of the Mohawk Valley, for it is extremely unlikely that that region escaped its deposition during the later transgressive stages of early Beekmantown time. I have elsewhere given at length my views on the character of the retreat and readvance, and I have not seen anything in the new facts brought forward since that time to cause me to change them. Indeed, I find that they rather confirm my frequently expressed views in this matter, which are rather widely at variance with those expressed by Ulrich and adopted by his followers. (See my *Types of Sedimentary Overlap* and *Physical and Faunal Evolution of North America in Ordovicic and Siluric Time.*)

[23] I hesitate to speak of this fauna as of Arctic origin, for although the indications are that the present Arctic region was its home, I do not believe that that region had its present relation to the North Pole of the earth's axis. The term Boreal is therefore chosen to represent this region as being non-committal so far as polar relation is concerned.

The fauna of the *Megalaspis limbata* limestone at the Kinnekulle does not occupy the whole of the Lower Red Orthoceras limestone, for a part of this rock, according to Moberg, falls into the Asaphus limestone. G. Holm, however, makes the Limbata limestone the equivalent of the Lower Red Orthoceras limestone of the Kinnekulle quarrymen. Under the term Asaphus limestone have been included all those beds in which species of Asaphus predominate over species of Megalaspis, and it would appear that the beds designated are not always exact equivalents in different sections. At the Kinnekulle the fauna of this division differs markedly from that of the Limbata limestone, though, as will be seen by a glance at the list of the Asaphus limestone fauna given above, the genus Megalaspis is still present. Indeed, that genus ranges through a considerable portion of the Orthoceras limestone, while with us the species referred to it are confined to the lower western Beekmantown, with the exception of one species described from the Lower Richmond of Iowa.

THE ORTHOCERAS LIMESTONE OF ESTHONIA

Before considering the Orthoceras limestone of northern Scandinavia, it will be well to note the characteristics of the equivalent formations in the Baltic provinces, Esthonia and Saint Petersburg, on the south side of the Gulf of Finland, and approximately due east from the Swedish locality just discussed. This section, which I have not visited myself, has been described in considerable detail by Fr. Schmidt, and more recently by Lamanski and by F. v. Huene (Centralbl. für Min., etc., 1904, No. 15).[24]

Bassler, in an elaborate memoir on the early Paleozoic Bryozoa of the Baltic Province, gives a summary of the section and a list of the species of fossils reported from these formations with an indication of their range in the several subdivisions of the series. This list, though in some respects faulty (see the criticism by Axel Born), nevertheless is of great value, and Bassler has performed a distinct service for which students of the early Paleozoic rocks owe him gratitude.

In this region the section begins with the Lower Cambric Esthonia formation (Marcou), which rests on the pre-Cambric granite or gneiss and has a thickness of 100 meters or more. It includes a basal sandstone and an intermediate thick layer of plastic blue and greenish clay, and is followed by sandy layers with intercalated clayey layers, which carry *Mesonacis* (*Schmidtiellus*) *mickwitzi*, *Mickwitzia moniliforme*, and *Volborthella*,

[24] Since this paper has been completed, the important paper on "The correlation of the Ordovician strata of the Baltic basin with those of eastern North America," by Percy E. Raymond, has appeared (Bull. Mus. Comp. Zool., vol. lvi, No. 3). Reference will be made to it in the following pages in footnotes.

as well as casts of medusæ and other fossils. This appears to be the equivalent of the Mickwitzia sandstone of the Kinnekulle section. The highest beds of the series consist of from 10 to 15 or more meters of an unfossiliferous sandstone, the apparent equivalent of the Lingulid sandstone of Westergotland. There is thus clearly indicated a westward and northward transgression of the Lower Cambric sea, with progressive overlap of the strata in that direction.

Middle Cambric beds are wanting, but the Upper Cambric[25] is represented by the Ungulite sandstone, which is about 20 meters in thickness, mostly unconsolidated, and characterized by *Obolus apollinus*. This horizon is widely represented in Sweden by the Obolus conglomerate, which in some sections (see Dalarne) lies at the base of the fossiliferous series, and is there included in the Ordovicic, and in others (for example, Oeland) lies on various members of the Middle Cambric, fragments of which it includes. The Obolus is generally found in the cementing lime sand, which in some sections includes also *Dictyonema flabelliforme, Agnostus pisiforme,* and Olenus (Grünicken on Œland, Moberg, *et al*). The Obolus conglomerate sometimes includes beds carrying *Agnostus pisiformis.*

We may judge from this that the Obolus conglomerate represents the transgressing basal bed of late Cambric-early Ordovicic time, and that the Dictyonema shale which follows it in Œland and in the Baltic Provinces is the next depositional member. Bassler, in his section, indicates a hiatus between the Ungulite and Dictyonema beds, but there seems to be no evidence for such a break. When the Dictyonema shale is absent, as at the Kinnekulle and in Dalarne, this may be due to non-deposition of the shales, their place being taken by early Ceratopyge limestones. *Dictyonema flabelliforme* was an Atlantic type, as shown by its abundance on both sides of that ocean, especially in Britain and in eastern North America. Ceratopyge, on the other hand, was a Pacific or Siberian type, represented in America only in the western (Pacific) deposits. It is thus perfectly possible that in different types of sediment at one and the same period members from the faunas of distinct oceans may have become buried, while the subsequent advance westward of the Ceratopyge fauna may have resulted in the overlapping of the beds carrying this fauna over the horizon of the Dictyonema fauna. It may be noted in this connection that in parts of England (Malvern Hills) *Dictyonema flabelliforme* ranges through a thousand feet of strata, while in Sweden the beds with Ceratopyge are as a rule of slight thickness. There are, of course,

[25] Raymond includes this with the Dictyonema beds in his Packerort formation, which he makes basal Ordovicic (p. 186). The presence of *Agnostus pisiformis* and Olenus, however, argues against this.

not wanting indications of a possible hiatus between the Ceratopyge beds and the Upper Cambric strata. One such we were enabled to study at Oedegarden, near Ekedalen, in Westergotland, under the guidance of Prof. Carl Wiman, of Upsala. The section herewith given is taken from my field notes and represents the Ceratopyge limestone—here intimately associated with, and indistinguishable from, the Planilimbata limestone—resting on the fetid limestone of the Olenus-bearing Alum shale series (Upper Cambric). The fetid limestone contains Peltura and Sphærophthalmus, and its upper surface is characterized by corrosion hollows which are often several centimeters deep, and are filled by the glauconitic Ceratopyge limestone. The two are so firmly united that it was possible to remove specimens showing both beds.[26] The base of the Ceratopyge limestone is characterized by brown phosphate nodules, which contain fossils of the underlying Stinkkalk and represent altered fragments of the same.

The Dictyonema shales are here wanting, as well as the zones of Acerocare and *Parabolina heres,* which in Scania have a thickness of 5 meters, and this and the corrosion grooves suggest temporary exposure of the Upper Cambric beds. I doubt, however, if this exposure was a long one; it represents more likely one of those numerous small oscillatory movements which seem to have characterized certain portions of the old land of Cambric and Ordovicic time, on the borders of which the strata of this period were deposited.

The Ceratopyge beds seem to be wholly wanting in Esthonia, where the Dictyonema shale is also occasionally absent. It, or the Ungulite sandstone below it, is followed by glauconitic sandstone, which Lamanski designates as Division B I of his series. This reaches its greatest thickness of 5.5 meters in the western area at Baltic Port, where the rock consists of rounded quartz and glauconite grains with fragments of crystalline rock and some bituminous shale pieces. Eastward it becomes thinner and more clayey, being mostly clay with intercalated sandy loam east of Saint Petersburg.

The contact between the base of the glauconite sand and the top of the Dictyonema shale is always sharp, since there is a slight erosion hiatus between them, as indicated by evidence of erosion in the shale and the

[26] According to Michalsky, this is the usual relation when glauconite rests on limestones. It has been noted in the Schratten Kalk of Switzerland and in the Jurassic limestone near Regensburg, in addition to the Ceratopyge horizon of Sweden. (The holes are often as if made with an augur and filled with glauconite. Cong. Geol. Int. Compt. Rend., sesion Stockholm, also Andersen, Bull. Geol. Inst. Univ. Upsala.) The Regensburg occurrence I was enabled to study with some care. Here the contact is between the Regensburg greensand of Cenomanian age and the Kehlheim limestone of Upper Jurassic age.

presence of worn pieces of shale in the basal part of the glauconite sand. The latter gradually becomes calcareous upward, until beds of glauconite limestone with *Megalaspis planilimbata* become intercalated between the sands, marking the beginning of B II.

The lower part of the Glauconite sandstone, B I *α*, contains *Obolus siluricus,* indicating relationship to the Ceratopyge limestone, which this sandstone probably represents.

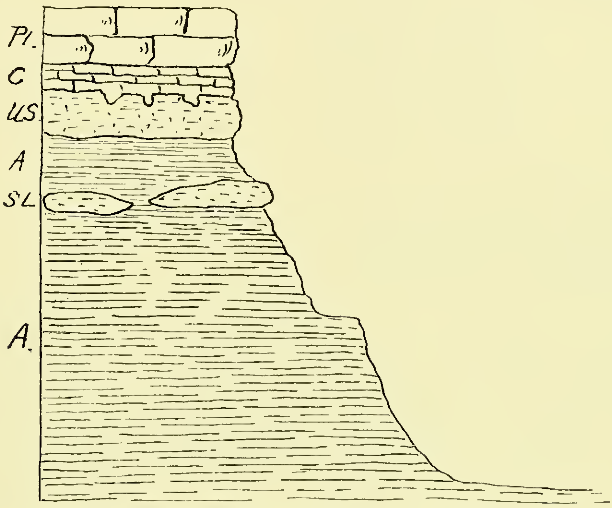

FIGURE 3.—*Section at Oedegarden, Sweden*

Showing contact between Ceratopyge limestone and Stinkkalk of the Upper Cambric. *Pl* = Planilimbata limestone; *C,* Ceratopyge limestone; *U S,* Upper Stinkkalk; *S L,* Stinkkalk lenses; *A,* Alum shale (Upper Cambric).

The upper division, B I *β*, is characterized by *Megalaspis leuchtenbergi* Lamanski, a close relative of *M. planilimbata,* of which it may be a prenuncial variety. Two other species, *Megalaspis bowni* Lamansky and *Megalaspides schmidti* Lamansky, a relative of *Megalaspides delecarliens* Holm, of the Phyllograptus shale of Dalecarlia, Sweden (Dalarne), also occur here. Other species are *Ptychopyge* (?) *inostranzewi* Lamanski and *Triarthrus* (?) *angelini* Linnarss. There are, further, numerous species of Orthidæ, of which the following are described by Lamansky:

Orthis recta Pander.
striata Pander.
transversa Pander.
transversa var. *latestriata* Lamansky.
incurva Lamansky.
christianiæ Kjerulf.

tetragona Pand.
var. *lata* Pand.
abscissa Pand.
bocki Lamanski.
parvula Lamanski.

Other brachiopods are:

Porambonites bröggeri Lamansky.
Plectella gracilis Lamanski.
unicata (Pander).
semiovata Lamanski.
media Lamanski.
eminens Lamanski.
extensa Lamanski.
obtusa Lamanski.

Besides these brachiopods there occur

Orthoceras atavus Brögg.
Siphonia (?) *cylindrica* Eichw.

Lamansky finds that the brachiopods of this horizon are divisible into two groups. The species of the first group are restricted to this horizon and do not pass upward into the overlying limestone. Here belong *O. recta, O. striata, O. christianiæ,* and *O. bocki.* Only two of these are found in Scandinavia, where *O. christianiæ* occurs in the Ceratopyge limestone, while *O. recta* has been found in the Obolus sandstone near Gefle. The other species of Orthis, as well as those of Porambonites and Plectella, extend upward into the overlying Planilimbata limestone, where they are for the most part represented by closely related mutations. Lamansky holds that the brachiopods referred to Orthis sp., Leptæna sp., Strophomena sp., etcetera, from the Ceratopyge beds, and the intercalated limestones of the Phyllograptus shales of Sweden may be of species above listed. Those brachiopods are somewhat suggestive of species found in the later Ordovicic (Trenton, etcetera) of North America and the equivalent west European horizons, suggesting that this element of the fauna had its center of distribution in the northeastern region, from which successive migrant groups were sent westward throughout Ordovicic time. We can, however, not follow Bassler in placing these lower deposits in the Middle Ordovicic on the basis of these brachiopod types.[27]

Among the trilobites, *Megalaspis leuchtenbergi* shows the close relation of this division to the succeeding beds with *M. planilimbata; Triarthrus angelini,* on the other hand, is a characteristic species of the Ceratopyge limestone of Sweden. The intimate relationship with the Phyllograptus

[27] Raymond also correlates these with the lowest Beekmantown.

beds of Dalecarlia, Sweden, is shown by *Megalaspides schmidti*, the representative of *M. dalecarlicus* of the limestone bands of the Swedish Phyllograptus shale. Finally, *Orthoceras atavus* Brögger is another characteristic species of the Ceratopyge limestone, having first been described from that rock in Norway.

Altogether it would appear that Division B I of the Baltic Provinces is the equivalent of the Scandinavian Ceratopyge limestone and shale, forming the near-shore phase of that division of the North European basal Ordovicic. This is borne out by the fact that this horizon is absent in the Bohemian area, where, however, its time equivalent may be represented by the Krůsnáhora sandstone with *Lingula feistmantelli*, a fauna probably of Atlantic origin. Ceratopyge has, however, been reported from the Thuringian forest region.[28] Lamansky holds that Division B I may be in part the equivalent of the Lower Phyllograptus shales, as shown by the fact that these shales contain limestones with Megalaspides, a genus also represented in B I β. For this horizon he proposes the name *Megalaspides* zone and places it between the Ceratopyge and the Planilimbata zones.

It may be desirable to repeat here the statement made above, that the Ceratopyge fauna is of Siberian origin, entering the Baltic region from the northeast, whereas the Dictyonema and Phyllograptus-Tetragraptus faunas are of Atlantic origin (or habitation), entering the same province from the west. Thus an overlapping of the faunas occurs, though, as found in Scandinavia, the Dictyonema always underlies the Ceratopyge beds, a circumstance which clearly shows that the Ceratopyge fauna entered this region subsequent to the arrival of the Dictyonema fauna, though it probably existed at the same time in the more easterly provinces.

Since the Phyllograptus shales normally follow on the Dictyonema shales, where the Ceratopyge beds are absent, they are to be regarded as, in part at least, the equivalent of the Upper Ceratopyge beds, though a portion of the latter may also be represented by Dictyonema shale. The fact that the Phyllograptus shales disappear eastward and northward (Œdegarden, in Westergotland, and Sjurberg, in Dalarne), while they are present westward (Kinnekulle, Christiania), where the Planilimbata limestone is absent, shows the derivation of the graptolite fauna to be from the west or Atlantic region.

The North Pacific or Siberian habitation of the Ceratopyge, as well as the Megalaspis faunas, is further shown by the recent discovery by Walcott[29] of *Ceratopyge canadensis* in the Lower Goodsir formation of British

[28] H. Loretz: Jahr. Preuss. Geol. Landesanst., 1881, p. 175.

[29] Cambrian Geology and Paleontology, vol. ii, No. 7, 1912. The correct generic determination of this trilobite has, however, been questioned.

Columbia (base of Ordovicic) with *Orthis mollinensis* Walcott, a form related to *O. salteri* Hall of the Ceratopyge limestone of Scandinavia, and by the fact that Megalaspis in America is practically confined to the early Ordovicic (Beekmantown) of the Pacific region (inclusive of the Rocky Mountains) of North and South America (two and four species respectively), though one species also occurs in the "erratics" in the Lèvis formation of Quebec and one is reported from the Richmond of Iowa.

Although Ceratopyge and Megalaspis are restricted to the Scandinavian-Russian region, other trilobites associated with them in the Norwegian region are widely distributed in the Atlantic province. These are Euloma, Niobe, Angelina, Asaphellus, Cheirurus, Cyclognathus, Parabolinella, Shumardia, Symphysurus, etcetera. Several of these are already found associated with Dictyonema in the Lower Tremadoc, while others characterize the Upper Tremadoc or the beds below the Phyllograptus shales. This trilobite fauna, designated by Brögger the Euloma-Niobe fauna, is also known from the Christiania region, Bavaria, southern France, Bohemia, Sardinia, and seems to be represented in eastern Canada. The presence of some of these genera in the Ceratopyge limestone of Westergotland (*Euloma ornatum* A., *Niobe insignis* Lns., *Symphysurus angustatus* Boeck, etcetera) suggests that they, like the Ceratopyge, are of North Pacific or Siberian origin. This may be true of some of the other trilobites as well, their distribution westward being more extensive than that of Ceratopyge. Some of them may have an Atlantic origin, but our present knowledge of their distribution does not permit us to form any more positive judgment in the matter.

It should also be recalled that another fauna, the typical Beekmantown fauna, existed at this time in the Champlain Valley, Newfoundland, and the north of Scotland, extending possibly to the Birikalk of Norway. There can be little doubt that this fauna had a distinct origin, since it is unknown from southern regions, or, for that matter, from any other portion of the Old World.

The following diagram represents the interrelation of the three faunas (figure 4).

Turning now to Division B II, the "Glaukonitkalk" of Fr. Schmidt (exclusive of the *Asaphus expansus* beds), we find that Lamansky has been able to recognize three distinct divisions, which he has designated from below upward B II α, B II β, and B II γ.

The first of these, B II α, is quarried on the Wolchow River near Saint Petersburg, under the name *Dikari*. The rock consists of limestone layers 13 to 27 cm. thick. These have a bright red, yellow, violet, or gray green color. The limestones have a thickness of 1.65 to 1.8 meters, but

the underlying green marly beds which form a transition to the Glauconite sand below (B I) also belong to this horizon. The fauna is especially characterized by *Megalaspis planilimbata* Ang. in the lower and *M. limbata* Sars. and Boeck, *M. polyphemus* Brögg., and *Asaphus priscus* Lamsk. in the upper part. Ptychopyge, Niobe, Ampyx, Illænus, and Cyrtometopis are also represented. Besides this there are a number of species of Orthis, many of them identical with or close mutations of the species found in the underlying B I β beds.

The second division, B II β, known locally as "Sheltjaki," consists of thin-bedded, less compact, mottled limestone with sporadic glauconite grains. Its thickness is 1.80 meters. It is especially characterized by *Asaphus bröggeri* Dalm. and *Onchometopus volborthi* F. S., and contains, besides two species of Megalaspis (*M. kolenki* F. S. and *M. hyorrhina*

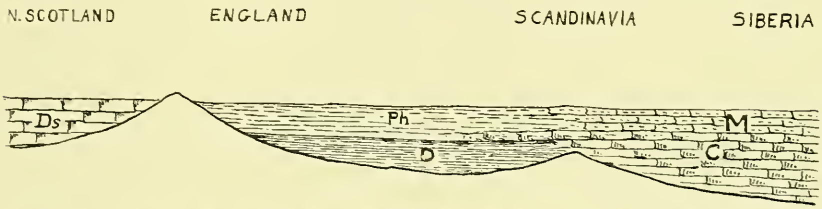

FIGURE 4.—*Ideal Section illustrating the Relationships of the several Types of Deposits in the north Scottish, Atlantic, and Siberian Provinces in Lower Ordovicic Time*

In the north Scottish region the Durness limestone facies (*Ds.*) with Beekmantown fossils occurs. In the central or English region (Atlantic province) graptolite shales predominate, the Dictyonema shales (*D*) being succeeded by the Phyllograptus shales (*Ph.*). In the eastern or Siberian region limestones predominate, with the Ceratopyge and earlier beds below (*C*), followed by the Megalaspis limestone (*M*).

F. S.), *Niobe lindströmi* F. S., *Nileus armadillo* var. *depressa* Sars. and Boeck, two species each of Cyrtometopus and of Illænus, and one each of Pterygometopus and Amphion. The generic relation of this trilobite fauna to that of the Ceratopyge horizon is evident, though the species are mostly distinct. Of the species of Orthis and Orthisina, some continue from the underlying beds, while all but one of the species of Porambonites found in B II β also occur in B II α, and all extend up into B II γ, but not above this horizon.

The third division, B II γ, consists of rather compact gray limestone, known locally as "Friese," and having a thickness of 2.40 to 2.70 meters. It is separated from the overlying B III α by a wavy surface above which glauconite abounds. This horizon contains a rich fauna in which *Asaphus lepidurus* and *Megalaspis gibba* are considered the leading types. Three other species of Megalaspis are found here, one of them continued from the bed beneath, as is also *Onchometopus volborthi* F. S., *Ptychopyge*

angustifrons Dalm., *Cyrtometopus clavifrons* Dalm., *Illænus centrotus* Dalm., and *Amphion brevicapitatus* Lamansky. Other species of these genera also occur. All of the brachiopods continue upward from the preceding bed or the one before it, and the same may be said of the crinoids, corals, and Bryozoa. On the whole, while all three divisions show relationship, B II β and γ are more closely related faunally, while B II a is closely bound to the preceding horizons of B I. There is, however, an absolute distinctness of species between horizons B II and B III, with the exception of the Bryozoa. Of the 31 trilobites of Division B II, only *Ptychopyge angustifrons* Dalm. is recorded from both B II and B III; but, as Lamansky points out, under this name are included many distinct mutations, which, when separated, would be found to be restricted to distinct horizons. None of the twenty brachiopods found in B II pass upward into B III, and the same is true of the 13 echinoderms and of the pteropods and cephalopods. Only among the Bryozoa seems there to be a continuance of species, not only between B II and B III, but also between B II and horizons above B III. Of the 12 species recorded by Bassler from B II, 7, or 58.33⅓ per cent, occur in B III or in C. Two of these range into the highest division of the Baltic series. Two species are American, found here in the Lower Trenton. Either sufficient care was not taken in the collection of the material on which Bassler based his determinations or the Bryozoa are not such good horizon-markers as has been assumed.[30]

The entire group B II is designated by Lamansky as the Megalaspis group,[31] while the succeeding division, B III, is designated the Asaphus group. This also consists of three divisions designated B III a, B III β, and B III γ, respectively, by Lamansky. The first is characterized by *Asaphus expansus, A. lamanskii,* etcetera; by species of Niobe, Illænus, Cyrtometopus, Metopias, and other trilobites. Among these, *Illænus esmarckii* Schloth. and *Cyrtometopus affinis* Ang., *Amphion fischeri* Eichw., and *Metopias pachyrrhina* Dalm. range through all these subdivisions.

B III a is also marked by the first appearance of *Orthis calligramma* Dalm., which ranges through the whole division and is wide-spread in the Upper Ordovicic of England (Caradocian), and the equivalent horizon

[30] See also Axel Borns' criticisms of Bassler's Bryozoa lists. Centralblatt für Min. Geol. u. Pal., 1913, p. 712. It should be remarked in justice to Bassler's work that the material on which he based his determinations was brought together by several collectors, and that he can not be held responsible for misplacement of horizons.

[31] Raymond has proposed the name *"Walchow formation"* for this division, but includes with it Division B I and Division B III a of Lamansky. This last is not justified, owing to the evidence of a break between B II γ and B III a, and especially because of the almost complete change of fauna as recorded by Lamansky.

in Galicia and elsewhere. In Sweden it occurs in the Lower Chasmops limestone of Dalecarlia. Another species of Orthis confined to B III α is *Orthis callactis* Dalman, which occurs in the Asaphus limestone of Dalecarlia. *Lycophoria nucella* Dalm. is another species appearing here for the first time and ranging through B III, and so is *Strophomena jentschi* Gay, important as characterizing the Asaphus limestones of Œland and the boulders of limestone conglomerate to be referred to later.

The second member of the Asaphus limestone, B III β, is a mottled yellowish to reddish limestone, with a thickness of about 3.5 meters. The fauna is not markedly distinct from that of B III α, but is especially characterized by *Asaphus raniceps* Dalm. Four species of Megalaspis occur here, including *M. acuticauda*, which also occurs in B III α, and has a related form in B II γ. *Megalaspis heros* Dalm. also occurs here, and *Asaphus expansus* Dalm. is continued upward from B III α. The

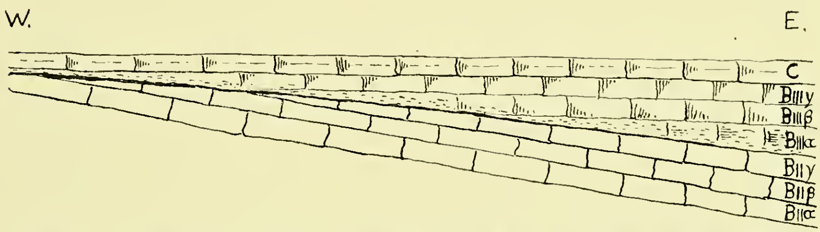

FIGURE 5.—*Diagram illustrating the westward Increase of the Hiatus between Divisions B II and B III in Esthonia*

(Modified after Lamansky)

horizon carries a thin layer of lenticles of brown iron oxide (Untere Linsenschicht) a short distance above the base, in which, according to Raymond, *Pliomera fischeri* and *Lycophoria nucella* are especially abundant.[32]

The upper division, B III γ, is a heavy bedded limestone, about 6 meters thick, and is especially characterized by *Asaphus eichwaldi* F. S. and *Ptychopyge* (*Pseudasaphus*) *globifrons* Eichw. This fauna differs more from the preceding two than do their faunas among themselves. Several of the trilobites, however, as well as a number of brachiopods, are common to all these divisions. The most marked character of this division is, however, the appearance of numerous Cephalopods of the genera Endoceras, Vaginoceras, Planctoceras, Estonioceras, and Cyrtoceras. The gastropods Raphistoma, Maclurea, and Salpingostoma also occur.

A second zone of phosphatic pebbles (Obere Linsenschicht) often separates this horizon from the succeeding Echinosphærites limestone, C 1.

[32] Raymond compares these "Linsen" to the disklike oolitic grains of the Clinton iron ore of North America. He places this and the succeeding Division B III γ in his *Kunda* formation, from which he, however, excludes Lamansky's Division B III α.

The fauna of this latter horizon in the Baltic Provinces is, according to Lamansky, very distinct, not a single species found in any member of Division B passing upward, while many new genera make their first appearance.

Physically the two divisions, B II and B III, are separated by a hiatus which shows an increasing magnitude westward (figure 5). This is indicated by the progressive failure westward of the upper members of B II and the lower members of B III, until near Baltic Port both series are chiefly represented by their extreme members. B II at this point shows a much eroded surface and is followed by a conglomerate and sandstone containing fragments of the underlying bed and resting variously on B II α, B II β, or more rarely on B II γ. The sandstone represents B III γ, so that B III β and B III α are wanting through overlap. Evidently after the deposition of the three members of B II an eastward retreat of the sea followed, resulting in the laying bare of the deposits which were then eroded. After this they were progressively covered again by the transgressing sea, with the successive deposition of the westward overlapping members of Division B III. Thus B III α fails in the vicinity of Saint Petersburg and B III β in the neighborhood of Reval, each in turn being overlapped by the succeeding formation. The Chasmops or Echinosphærites limestone alone is continuous and without marked lithic change over this area.

Eastward of Baltic Port the base of the upper series (B III γ) is a limestone with a basal phosphatic conglomerate formed of fragments of the underlying Megalaspis limestone. At Putilowo the Megalaspis beds still show marked erosion, followed by a glauconitic conglomerate, while beds with *Asaphus expansus* (B III α) begin to appear. Still farther east the surface of the underlying bed is smooth, and the contact is marked only by glauconite grains in the overlying bed. The glauconite grains above this contact show evidence of attrition, as do also the fossils found in B III α in this region, these being often strongly worn and frequently broken.

That the hiatus between B II and B III is greater than is indicated by the physical break described is evident from the complete change in fauna, and it is hardly to be questioned that, if proper exposures occurred farther east in Russia, not only would additional beds be found above B II γ—that is, below the break—but others below B III α—that is, above the break. I have elsewhere[33] correlated this progressive-transgressive movement with the one I had established in the North American

[33] Physical and Faunal Evolution of North America, etc. Journ. Geol. and Outlines of Geological History, edited by Willis & Salisbury, p. 65, 1910.

series between the Beekmantownian and Chazyan. The Megalaspis beds of the Baltic region, B II, thus correspond to the early Beekmantown of the Mohawk Valley and the Upper Mississippi, as is also shown by the intimate relation of the Megalaspis beds to the preceding basal Ordovicic Ceratopyge horizon. In the same manner they correspond to the Lower Magnesian series of the Upper Mississippi Valley, which is separated from the Upper Chazyan Stones River beds (*Plattville limestone*) by the St. Peter sandstone, shown by Berkey and myself to represent a continental deposit (chiefly eolian) formed during the long interval of exposure. This St. Peter hiatus, as we may designate it, is therefore recognizable on both sides of the Atlantic, and since it is also marked in the Rocky Mountain region (Harding sandstone horizon) and in Nevada (Eureka quartzite horizon), it must be regarded as indicating a universal compound eustatic movement, and should be shown in other parts of the world. The evidence for its existence in England and Bohemia will be considered later.

What the age of the Asaphus beds overlying the hiatus is, is less readily determined. Bassler, on paleontological grounds, correlates it with the Lowville; but he also places the Glauconite limestone in this horizon, which we have just shown to be of early Beekmantown age.[34] The exact equivalency can only be determined from the relationships shown in Scandinavia, though it may be well to call attention again to the appearance in this horizon of *Orthis calligramma,* a characteristic Caradocian brachiopod.

CORRELATION OF THE EAST BALTIC AND SCANDINAVIAN HORIZONS

Returning now to the Swedish occurrences of the Orthoceras limestone, which term, unlike its use in the East Baltic region, where it comprises only the Asaphus horizon, B III, includes in Sweden the Megalaspis beds (B II), we must first turn our attention again to the Westergotland sections and attempt to correlate the subdivisions there found with those of the East Baltic Provinces. It is evident that the Lower Red Orthoceras limestone with *Megalaspis limbata* corresponds to B II α of the Baltic region, while the Lower Chasmops limestone with *Echinosphærites aurantium* corresponds to C 1 of the Baltic Provinces. This leaves all of the higher Orthoceras limestone to be correlated with the intervening divisions. Incidentally, it may be recalled that the Limbata limestone is separated from the Ceratopyge beds by the Lower Didymograptus shale.

[34] Raymond, who designates the upper beds (B III β and B III γ) by the name of Kunda formation, makes them equivalent to the Upper Beekmantown of America. In this I strongly disagree with him. They are of late Chazyan, if not of younger, age.

with Tetragraptus, Didymograptus, and Phyllograptus (Lower Deepkill of America), and that this shale therefore replaces the Planilimbata limestone.

The Asaphus limestone immediately succeeding the Limbata limestone in Sweden is the equivalent of a part of B III of Esthonia; hence the zones B II β and B II γ are wanting in Westergotland, and the lower Middle Ordovicic hiatus (St. Peter hiatus) falls immediately above the Limbata beds. The fossils of the Asaphus limestone, which serve to correlate it with the East Baltic formations, are *Megalaspis heros* Dm., which occurs in the *raniceps* and *eichwaldi* zones (B III β and B III γ) of Russia, *Illænus esmarkii* Schloth. found in all three divisions of B III, and *Ampyx nasutus* Dm., which occurs in B III α and the lower and middle part of B III β. *Asaphus raniceps*, the zone fossil of B III β, is represented in the Asaphus limestone of the Kinnekulle by variety *maxima* Br.

From these considerations it would appear that the Asaphus limestone represents the middle and perhaps part of the upper division of the Russian Orthoceras limestone (B III β and B III γ a). The absence of *Asaphus expansus* certainly suggests the absence of the lower zone, B III α, though this seems to be represented in the Christiania region (Expansus shale) and in Dalarne, where it rests on the Limbata limestone.

That the line of division is not definitely drawn in the Kinnekulle region is shown by the occurrence within the Asaphus bed there of *Cyrtometopus clavifrons* Dal., a form characterizing all three members of Division B II in the South Baltic region. It is highly probable that the part in which this is found belongs to the Limbata limestone, the extent of which is thus equivalent to that of the Lower Red Orthoceras limestone as held by G. Holm.

The Gigas limestone of Westergotland may represent the upper part of B III γ or the lower part of C I α. This latter division includes the Platyurus limestone, as shown by the presence of *Asaphus platyurus* A., while the Chiron limestone, with *Illænus chiron* Hm., represents the horizon C I β of the East Baltic region. The succeeding Chasmops limestone probably represents the remainder of the Echinosphærites bed or C I γ of the Baltic region, and perhaps C II as well. It contains *Ampyx rostratus* Sars., which ranges from C I β to C II and *Echinosphærites aurantium* Gyllenh., which ranges through all divisions of C (Echinosphærites, Kuckers, and Ifter beds), and is reported from the Jewe and Wassalem beds (D I and D III) as well.

The Trinucleus shale following this series of limestones contains a fauna which has no representation in the East Baltic region, and the

same is true of the beds referred to the Brachiopod shale at the Kinnekulle. The abundance of Trinucleus, Staurocephalus, and Dionide in the former and of Dalmanites, Lichas, and Homalonotus in the latter, all genera absent or rare in the East Baltic regions, suggest Atlantic affinities. The same origin probably holds for the Graptolite fauna of the Upper Graptolite shale (Siluric).

In Östergotland, east of Lake Wettern, the Dictyonema shale has a thickness up to 3.5 meters, its base being everywhere a sandstone, which at Vestano is more than 2 meters thick. This has been regarded as the *Obolus* sandstone by Wiman, though the characteristic fossils have not been found in it.[35] The Ceratopyge limestone seems to be represented by a glauconitic marl. The Orthoceras limestone, quarried since the beginning of the nineteenth century, has furnished many of the types of trilobites described by Dalman and comprises in descending order:

Expansus limestone, greenish to red.
Gray limestone.
Heros limestone (with *Megalospis heros* A.).
Reddish limestone.
Planilimbata limestone.

Underlain by greenish marl and Dictyonema beds, as previously noted. *Megalaspis heros* is characteristic of the Raniceps and Eichwaldi zones of the East Baltic region (B III β and B III γ), but has not been recorded from the Expansus zone. The reddish limestone is probably the Limbata limestone, and this would place the break between this bed and the Heros limestone. However, the occurrence of the Expansus limestone higher up suggests some irregularity of interpretation, unless the Heros limestone and the gray limestone above it constitute a part of the Expansus zone. The Orthoceras limestone is followed by the Chasmops limestone with its lower Echinosphærites division and the upper with *Chasmops macrourus* (Macrourus limestone), and then by Trinucleus shale and Brachiopod shale.

In Närke (Nerike), north of Lake Wettern, the break comes above the Planilimbata limestone, which rests on Shumardia shales (Ceratopyge horizon —). Beneath this is a glauconitic limestone with phosphatic nodules, which in turn overlies the Peltura zone of the Upper Cambric and cuts out the Dictyonema shales. The succeeding lower gray Orthoceras limestone appears to represent the raniceps horizon, B III β, the Expansus horizon being absent here.

[35] Moberg: Silurian of Sweden, p. 150.

LOWER ORDOVICIC OF DALARNE

This province shows several interesting developments of the earliest Ordovicic rocks, a part of which I was enabled to study under the guidance of Dr. Elsa Warburg and Prof. Carl Wiman, both of Upsala. Important sections have been worked out by G. Holm,[36] S. L. Tornquist (1883-1884), H. Hedström (1894), F. v. Huene (1904),[37] and Carl Wiman (1906). Marr[38] has also added some interesting facts regarding this district.

In the environs of Nittsjö, on the eastern end of Siljan See, some of the most complete sections are seen. These are best approached from the village of Rättvick, which lies on the shore of the lake, which is here

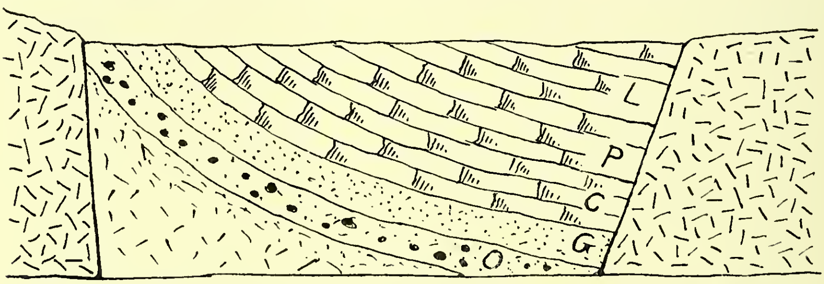

FIGURE 6.—*Section of the Lower Ordovicic Formations shown in the Railroad Cut near Sjurberg, in Dalarne, Sweden*

From a sketch by the author. Paleozoics are faulted into the granite mass, the fault block showing at the base fresh granite, which passes upward into decomposed granite. This is succeeded by the Obolus conglomerate (*O*), the Glauconitic sand (*G*), and the limestone comprising the Ceratopyge bed (*C*), the Planilimbata limestone (*P*), and the Limbata limestone (*L*).

skirted by the railroad. About 4.5 kilometers northwest of Rättvick station, by the road which parallels the railroad, and less than a kilometer beyond the little settlement of Sjurberg, there is found in the railroad cut an interesting section which is here reproduced.[39]

The top of the granite basement of the series consists of from 0.1 to 0.4 meters of weathered granitic material, which passes upward into an irregular bed of fine conglomerate, mostly with quartz pebbles and granite

[36] Ueber einige Trilobiten aus dem Phyllograptus Schiefe Dalekaliens. Bit. K. v. Akad. Handl., Stockholm, 1882, Bd. 6, No. 9.

[37] Centralblatt f. Min., etc., 1904, No. 15.

[38] J. E. Marr: On the Cambrian (Sedgw.) and Silurian rocks of Scandinavia. Quarterly Journal Geol. Soc., London, 1882, p. 315.

[39] H. Hedström: Geologiska notiser från Dalarne I. Stockholm, Geol. För. Förh., Bd. 16, 1894, pp. 585-593. Ibid., Till fråg an om fosforitlagrans uppträdlandi och förekomst. ide geologiska formations. Ibid., Bd. 18, 1896, pp. 65-70.

Wiman: Om ceratopygeregionen inom Siljansilnren. Ibid., Bd. 28, p. 453.

And Warburg's Guide to Excursions, C_2C_5, 10th Intern. Geol. Cong. (No. 21), p. 3.

fragments, and contains the phosphatic fragments and entire shells of *Obolus apollinis* Eichw. and grains of phosphatic nodules. This is the Obolus conglomerate (Ungulite sandstone) found in many places at the base of the Ordovicic. It ranges in thickness from 0.15 to 0.80 meter and passes upward into a glauconitic sand of about 0.1 meter thickness, which also contains fragments of these shells, and which in turn is succeeded by gray, somewhat glauconitic limestone—the Ceratopyge bed. This is characterized by *Lycophoria lævis* Stolley, and in it I found a specimen of *Eorthis christianiæ*. Small fragments of Obolus still occur.

The Ceratopyge bed passes without break into the Planilimbata limestone, and this into the Limbata limestone, these being all of the same kind of calcareous sediment with the characters of a typical calcilutite. The scarcity of organisms in this rock suggests that it may be a comminuted algal deposit, though no trace of such is found. The section is terminated by a fault.

The Ordovicic succession of this region in its entirety is as follows, in descending order:

Leptæna limestone.

Hiatus—disconformity.

Trinucleus shale.

d. Red calcareous Trinucleus shales .... 15 m.
1. *Remopleurides dorsospinifer* Portl.
2. *Prœtus brevifrons* Ang.
3. *Agnostus trinodus* Salt.

c. Gray limestone with fragments of fossils .... 5–9 m.
Trinucleus.
Orthis.

b. Black bituminous Trinucleus shale .... 6 m.
1. *Trinucleus seticornis* His.
2. *Calymene trinucleina* Linrs.
3. *Remopleurides radians* Barr.
4. *Orthis argentea* His.
5. *Leptana quinquecostata* McCoy.
(Numbers 1, 3 are characteristic of Dd_5 of the Bohemian succession.)

a. Masüre limestone or Knyckelkalk .... 9–15 m.
Gray, very hard, knobby limestone with calc spar veins.
No fossils.

Chasmops limestone.

b. Macrourus limestone and shale .... 9 m.
Chasmops maximus Schmidt.
Illænus linnarssoni Holm.
Ill. parvulus Holm.

a. Cystidean limestone .... 15 m.
Chasmops oldeni Eichw.

Leptæna convexa.
Platystrophia dorsata His.
Caryocystites granatum Gyllenh.
Echinosphærites aurantium Gyllenh.
Monticulipora petropolitana Pand.

Orthoceras limestone (restricted).

Ancistroceras limestone.. 5 m.
Illænus crassicauda Wahl.
Nileus armadillo Dalm.
Asaphus rusticus Tqt.

Chiron limestone.. 5 m.
Nileus armadillo Dalm.
Illænus chiron Holm.
Asaphus tecticaudatus.
Asaphus brachyrachis Remelé.
A. densistris Tqt.
Megalaspis formosa Tqt.
Endoceras bellemnitiforme Holm.

Platyurus limestone.. 13 m.
Asaphus platyurus Ang.
Endoceras bellemnitiforme Holm.

Gigas limestone.. 12 m.
Megalaspis gigas.

Asaphus limestone.. 8 m.
Asaphus expansus Wahl.
A. vicarius Tqt.
Megalaspis polyphemus var. *tornquisti* Schmidt.
Illænus esmarki Schloth.
Nileus armadillo Dalm.
Orthis callactis Dalm.
Orthisina ascendens Pand.
Lycophoria nucella Dalm.
Bucania planorbiformis (Linns.)
Salpingostoma cristatum (Linns.)
Lytospira angelini Lindst.
Vaginoceras vaginatum (Schloth.)

Hiatus—disconformity.

Megalaspis limestone.

Limbata limestone.. 3. m.+
Megalaspis limbata Boeck.
Niobe læviceps Dalm.
Nileus armadillo Dalm.

Planilimbata limestone.. 3. m.+
Megalaspis planilimbata Ang.

Ceratopyge limestone.

Limestone .... 0.14–0.16 m.
Obolus fragments.
Lycophoria lævis Stolley.
Eorthis christianiæ.

Glauconite sand	0.1 m.
Obolus conglomerate	0.15–0.80 m.
Obolus apollinis Eichw.	
Hiatus—unconformity.	
Basement beds.	
Weathered granite	0.1 to 0.4 m.
Fresh granite.	

The beds above the Megalaspis limestone, or the divisions of the Orthoceras limestone in the restricted sense, are well exposed on the shore of the lake just beyond this cutting, and here a good collection of the typical fossils, especially the Orthoceracones, may be obtained. The lowest of these beds, and the one directly succeeding the Limbata limestone, wherever this is found in contact, is the Asaphus limestone with *A. expansus* Wahl, *Vaginoceras vaginatum,* and the other species noted above. Most of these species are also found in the Esthonian region, where they are confined to B III and higher beds. Since so many of them are characteristic of B III a, the *Expansus limestone,* and since *Asaphus expansus* also occurs in this limestone of Siljan Lake, it is evident that the series begins with that division. Thus the divisions B II β and B II γ found in the Russo-German Baltic provinces are omitted here, and the hiatus in Dalarne falls above the *Megalaspis limbata* bed. The total thickness of the Asaphus limestone is about 8 meters, and it is succeeded by the limestone with *Megalaspis gigas* (12 meters) and the higher beds. These higher beds are exposed in a more or less continuous section in the vicinity of Nittsjö, something over a kilometer northeast of the railroad cut just described.

An interesting section occurs at Skattungbyn, near the northern end of Siljan Lake, and about 40 kilometers northwest of Rättvick.[40] This we did not visit, but it is significant in our discussion. The base of the section is a layer of green limestone a foot in thickness and resting directly on porphyry, of which it incloses angular fragments. This is followed by green Phyllograptus shales with layers of limestone. The shales contain *Tetragraptus serra* Brongn., *T. quadribrachiatus* Hall, *T. curvatus* Tqt., *Phyllograptus densus* Tqt., *Dichograptus octobrobrachiatus* Hall, *Didymograptus minutus* Tqt., *D. gracilis* Tqt., *D. decens* Tqt., and some brachiopoda. From the inclosed limestone layers Holm has obtained *Pliomera tornquisti* Holm, *Megalaspides dalecarlica* Holm, *Niobe læviceps* Dalm., *Ampyx pater* Holm, *Agnostus törnquisti* Holm.[41]

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[40] Törnquist: öfversigt öfver bergbyg-gnaden inom Siljasområdet i Dalarne. S. G. U., Ser. C, No. 57; Warburg., E. Guide, pp. 5-6.

[41] Holm: Ueber einige Trilobiten aus dem Phyllograptuschiefer Dalekarliens, Bih. K. V. Akad. Handl., Stockholm, 1882, vol. 6, No. 9.

The graptolites are evidently the equivalent of the Lower Arenig of Britain and of the Lower Deepkill of America. As already noted, *Megalaspides delecarlica* is a close relative of, if not identical with, *M. schmidti*, from the upper part of B 1 β of the East Baltic region. *Niobe læviceps* also occurs in East Baltica in B I β and B II α. The basal limestone of Skattungbyn is regarded by Wiman as the Ceratopyge limestone.

ORDOVICIC OF JÄMTLAND

Strangely enough, Phyllograptus shale is present in Jämtland, though unrepresented in the more southerly regions. This seems to be an expansion from the Christiania region passing to the west of the Nittsjö region in Dalarne (eastern end of Siljan See), but including the northern end of the Dalarne Paleozoic province (Skattungbyn). The shale has already been referred to as carrying intercalated limestone bands with the Megalaspides fauna, and thus serving to bring the two facies from east and west together. Moberg has found a representative of the Ceratopyge limestone as a thin bed overlying the Upper Cambric in some sections. In this he found *Eorthis christianiæ* Kjerulf, *Niobe læviceps* Ang., and *Cyrtometopus* cf. *foveolatus* Ang. In another bed he found *Niobe insignis* Linrs. and *Megalaspis stenorhachis* Ang.?

The Orthoceras limestone of Jämtland is particularly well developed in the country north of Brunflo, and between that place and Östersund. It has much the character which it possesses in Westergotland, that is to say, it represents both the lower *Megalaspis limbata* division, which belongs to the Lower Ordovicic, and the *Asaphus-Gigas-Platyurus* division, which belongs to the Upper Ordovicic. Here, then, as in Dalarne and in Westergotland, the Orthoceras limestone includes within itself the hiatus which represents practically the whole of the Middle Ordovicic (Chazyan of the American scale) and a part of the Lower Ordovicic as well. In thickness the limestone varies from 37 cm. in the Brunflo region to 90 meters in Klöfstjo and Skalängen.[42]

A peculiar development of the basal part of the Ordovicic is found in the Locknesjö Lake region of Jämtland and has been described in detail by Wiman.[43] Resting directly on the granitic basement is a breccia and residual arkose derived from the decomposition of the underlying rock. This is locally known as "Loftar stone," and it is succeeded by the Orthoceras limestone, a part of which it may actually replace. The following section (figure 7), given by Wiman, shows the relation of these beds.

[42] Moberg: "Silurian of Sweden," p. 146.

[43] Carl Wiman: Ueber die Silurformation in Jämtland. Bull. Geol. Institute, University Upsala, vol. iv, pt. 2, 1899.

The restoration in terms of original sedimentation, as I conceive it, is shown in the second diagram (figure 8).

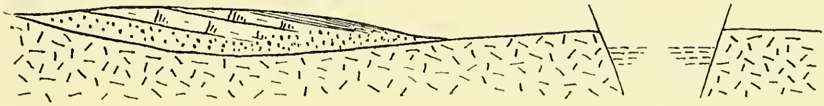

FIGURE 7.—*Section of Crystallines and Early Paleozoics in the Locknesjö Lake Region, Jämtland, Sweden*

Showing the "Loftar stone" resting on the crystallines and followed by the Orthoceras limestone. (After Wiman)

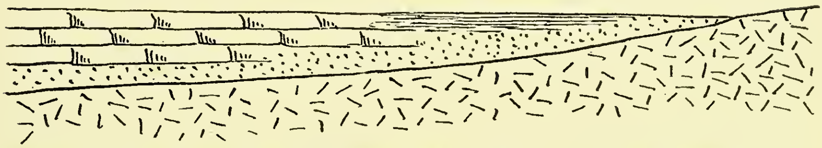

FIGURE 8.—*Ideal Section showing Relationship of Beds of preceding Section before Deformation and Erosion*

LOWER ORDOVICIC OF THE CHRISTIANIA REGION

This region is nearer the meeting ground of the Atlantic and Siberian faunas, and hence we find a more pronounced representation of both. The section of the Ordovicic strata comprises the following:

Superformation—Etage 6. Siluric.

Ordovicic.

		Feet
Etage 5 b.	With *Meristella crassa.*	
	Hiatus and disconformity.	
Etage 5 a.	Calcareous sandstone.	
	5 a and b range from........................	150–370
Etage 4.	Shales and marls with Trinucleus, Chasmops, etcetera	700
Etage 3 c λ.	Orthoclase limestone.........................	8–13
Etage 3 c β.	Expansus shale...............................	10–15
	Hiatus—disconformity.	
Etage 3 c α.	Megalaspis limestone.........................	3–4
Etage 3 b.	Phyllograptus shale..........................	8–80
Etage 3 a λ.	Ceratopyge limestone.........................	3–5
Etage 3 a β.	Ceratopyge shale.............................	3–23
Etage 3 a α.	Symphysurus shale and limestone..............	1–20
	Hiatus—disconformity.	

Upper Cambric.

The Phyllograptus shale here represents the Planilimbata limestone. It is followed by the limestones with *Megalaspis limbata* (3 c α),[44] and

[44] The notation here is distinct from that used in Esthonia.

these by shales with *Asaphus expansus* (3 c β), above which lie in turn the Gigas and Platyurus beds (3 c γ) with *Megalaspis gigas* and *Asaphus platyurus*. The succession is thus as in Dalarne, with the hiatus between the Limbata and Expansus horizons, the chief difference being the replacement of the Planilimbata limestone by Phyllograptus shale and the greater development of the Ceratopyge beds.

ORDOVICIC OF ŒLAND

This island, situated off the southeastern coast of Sweden, shows certain significant sections which are corroborative of the correctness of the general thesis so far developed. The Cambric, well developed in its middle facies, is disconformably succeeded by the Obolus conglomerate, which rests on successively lower members of the Middle Cambric from south to north. This conglomerate contains angular fragments of the underlying Cambric beds, those in the northern region carrying the remains of *Paradoxides tessini*. The cement of the conglomerate contains *Dictyonema flabelliforme, Obolus* cf. *apollinus,* Olenus sp. *Agnostus pisiformis* and var. *obesus*. The Dictyonema is found only in the cement of the upper part of the conglomerate, which is generally succeeded conformably by Dictyonema shale, except where this species occurs in the cement of the conglomerate. This suggests that the two formations are more or less contemporaneous, the Obolus belonging to the eastern fauna and the Dictyonema to the western.

The Ceratopyge limestone rests conformably on the Dictyonema shale when this is present, its base, as at Ottenby, on the south end of the island, being sometimes represented by an alum shale (Ceratopyge shale) carrying *Shumardia pusilla* Sars. and *Ceratopyge forficula* Sars., similar to the Christiania development. The Ceratopyge limestone is succeeded conformably by the Planilimbata and Limbata limestones with their characteristic fossils as elsewhere developed. This in turn is succeeded by the Asaphus limestone, which is divided into a lower and an upper bed, separated by a zone of limestone crowded with the globular cystoid *Sphæronis* (*Holocystites*) *pomum* Gyllenh. The lower bed seems to be identical with the Asaphus limestone of the mainland, but *Asaphus expansus* has not been found in it. It contains, however, *Strophomena jentschi* Gagel at several places in northern Œland. In the same rock Holm is reported to have found a specimen of *Didymograptus* (*Isograptus*) *gibberulus* (*I. caduceus* Salter). This is an Arenig species, while *Strophomena jentschi* suggests Upper Ordovicic affinities. If the latter is correct, then the break in the series comes here, as elsewhere in Sweden, above the *M. limbata* limestone, the next succeeding bed being

probably the equivalent of B III β of the East Baltic region. The succeeding beds of Œland, from the Gigas to the Ancistroceras limestone, are similar to those of Dalarne and elsewhere.

The S. jentschi conglomerate.—As having an important bearing on the correlation of the Œland strata, there should be mentioned the occurrence in parts of Sweden and elsewhere of a conglomerate in the matrix of which *Strophomena jentschi* is a characteristic fossil.[45] The cement "is a light gray limestone, partly coarsely crystalline, partly compact, more rarely merging into a coarse-grained, glauconitic sandstone with calcareous spar cement."[46] Besides *S. jentschi* it contains *Platystrophia biforata* Schloth, *Illænus* sp., and others. This would indicate the Caradoc or Trenton age of this bed, as well as that of the Lower Asaphus limestone of Œland. The pebbles of the conglomerate are phosphorites and phosphoritic sandstones, the former bearing fossils of Upper Cambric age. "The conglomerate was first observed by Gagel (1890) as boulders [*Geschiebe*] in East Prussia, but its age could not be determined until J. G. Anderson had proved the occurrence of *S. jentschi* in the Lower Asaphus limestone . . . in northern Œland."[47] Subsequently the boulders were found at Stonåsa, in Œland, at Gotland, and elsewhere, thus showing a wide distribution. The home of the conglomerate is probably in northern Sweden, where it rested on Cambric strata, and it probably indicates the wide-spread overlap of the readvancing Upper Ordovicic sea over the eroded surface exposed by the preceding retreat. As this seems the only rational explanation, and as the associated fossils in the matrix stamp the conglomerate as Upper Ordovicic, the finding of *Didymograptus caduceus* in the bed with *S. jentschi* on Œland (if this did not come from a lower layer) suggests that this may be a case of inclosure of Arenig from an underlying source comparable to the inclosure of fragments with Cambric fossils in the *S. jentschi* conglomerate.

ORDOVICIC OF SCANIA

General discussion.—This region, in the extreme southern end of Sweden, is of interest because it shows the dominance of the Graptolite facies of the Ordovicic series. There is some difference of development between the eastern and western sections, as brought out by Moberg's detailed studies. It was my good fortune to spend the better part of a week in the study of these Scanian deposits under the able and enthusiastic guidance of the late Prof. J. C. Moberg, of Lund University, whose

[45] J. G. Anderson, 1896: Ueber die Cambrische und Silurische phosphorit-führende Gesteine aus Schweden; also Moberg: "The Silurian of Sweden," p. 108.

[46] Moberg: Loc. cit.

[47] Moberg: Loc. cit., p. 119.

profound knowledge of the region made him the leading authority in this field, and I wish to record here his zeal and eagerness in guiding us, so that we should miss none of the important localities of the district. His untimely death is a hard blow to Swedish science and is regretted in America as well as in his native land. In the following descriptions I follow him closely, with only occasional additions of my own; for the interpretations, however, I alone am responsible.

East Scania.—The eastern region is shown especially well in the sections between Tommarp and Jerrestadt, the latter lying about 3 kilometers east of the former. Some of the best exposures are found along the creek passing through the two localities, but only in the more westerly area (Tommarp) are the exposures continuous. In the Jerrestadt region we found only scattered exposures, and some of the beds we could study only after removing the surface soil. Professor Moberg's intimate knowledge of the region here stood us in good stead, but we were not certain that the succession might not be interfered with by unrecognized faults, in which this entire region abounds. At Tommarp, however, the succession was clear and faults were eliminated.

The Dictyonema shales are shown in the exposure near Jerrestadt at several places and appear to lie directly on the Acerocare beds of the Upper Cambric, though the contact is not shown. In the lower beds *Dictyonema flabelliforme* Eichw. occurs, and higher up *Clonograptus tenellus* var. *callavei* Lapw. and var. *hians* Mbg., as well as *Bryograptus hunnebergensis* Mbg., while in the highest part occurs the subzone with *D. flabelliforme* var. *norwegica* Kjerulf and *Bryograptus kjerulfi* Lpw. These beds are succeeded by alum shales carrying *Ceratiocaris scanicus* Westergard, and believed to be the equivalent of the Shumardia zone of the Ceratopyge shales, while the limestone immediately succeeding them is classed by Moberg as Ceratopyge limestone, though typical fossils have not been found in it. Above this follow the Lower Didymograptus shales, the zone with *Didymograptus balticus, D. geometricus* Törnq., *D. constrictus* Hall, *Tetragr. quadribrachiatus,* and *Schizograptus rotans* Törnq., following directly on the supposed Ceratopyge limestone. Then follow Törnquist's zones *c* with *Phyllograptus densus* Törnq. (= *P. angustifolius* Hall) and *d* with *Isograptus gibberrulus* Nich. (*Didymograptus caduceus*). All of these represent Lower Arenig. They are succeeded by Orthoceras limestone, apparently representing the *Megalaspis limbata* beds, but this is not definitely ascertained. Somewhat higher, after a covered interval, occur shales with *Dicranograptus clingani* Carr., *C. bicornis* Hall, *Diplograptus quadrimucronatus* var. *spiniger* Lapw., *Lasiograptus margaritatus* Lapw., and *Corynoides calicularis* Nich. Higher

up occur *Diplograptus foliaceus* var. *calcaratus* Lapw. and *Dicellograptus forchhammeri* Gein. We have thus the Dicellograptus or Normanskill shales following almost directly on beds of Deepkill (Arenig) age, as in eastern North America, but with a thin limestone, probably representing the *Megalaspis limbata* beds, intervening. If this limestone is correctly identified, the break in the series comes above it, this break representing the greater part of the Arenig and of the Lower Llandeilo, or, in American terms, most of the Beekmantown and the whole of the Chazy.

A nearly continuous section is exposed in the stream bank south of Tommarp, which I here reproduce from my notes (figure 9). The beds dip at a gentle angle to the north, this dip being lowest at the southern end of the section. Here a quarry has been opened in the "Orthoceras limestone," which here represents the *Megalaspis limbata* limestone. The

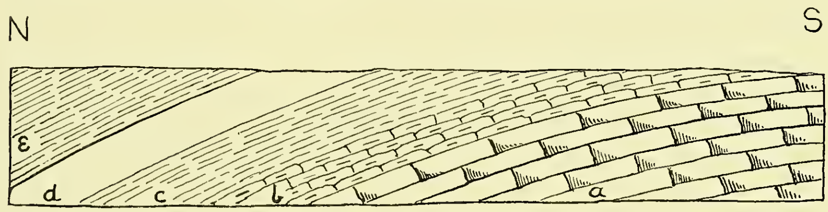

FIGURE 9.—*Section in the Stream Bank south of Tommarp, Scania, in southern Sweden*
a, Megalaspis limbata limestone; *b, Trinucleus coscinorhinus* beds; *c,* black shale with *Dicranograptus clingani; d,* covered; *e,* Trinucleus shale

limestone is in thin layers with shaly partings, the whole dipping about 20° to the north. Fossils are scarce, but I succeeded in finding a specimen of the pygidium of *Megalaspis limbata.* This limestone is followed by thin-bedded, dark, mainly black, fine-grained calcarenites, from which *Trinucleus coscinorhinus* Ang. and some other fossils have been reported. We, however, did not succeed in finding any of these.

Overlying this limestone are dark shales with *Dicranograptus clingani,* from which we also obtained some small brachiopods. After a covered interval, which may represent the zone of *Pleurograptus linearis* Carr. which we saw at Jerrestadt, a similar black shale with thin limestone beds completes the section. This is the zone of Trinucleus, the base of which is marked by a layer of iron pyrite concretions.

In spite of the good exposures (for Scania) of these beds, it was not possible for me to obtain any satisfactory physical evidence of the break in this section. It is perfectly clear that the break exists, since all the representatives of the later Arenig and early Llandeilo are absent. Even if the zones are represented in western Scania, a number are wanting here, these being, in ascending order, the zones of *Phyllogr. typus* and *Didy-*

mogr. geminus of the Upper Didymograptus shales, and the zones of *Glossograptus hincksi,* of *Diplogr. linnarssoni,* of *Diplogr. putillus,* and of *Nemagraptus gracilis,* or the whole of the Middle Dicellograptus shales, regarded by Moberg as the equivalent of the Chasmops beds of more northerly localities in Sweden. The zone with *Trinucleus coscinorhinus* is placed by Moberg below that of *Phyllograptus typus* from the relations believed to exist in West Scania. If this is the case, the break in the series comes above these limestones, and it must be confessed that the field indications seem to favor this, the contact between the shales and the limestone appearing a more likely place for a disconformity than between the two limestones. It must be remembered, however, that the position of the *Trinucleus coscinorhinus* limestone below the Phyllograptus shale in West Scania is by no means positively established, and that Tullberg has found *Ampyx rostratus* in the *T. coscinorhinus* zone, which he therefore regards as belonging to the horizon of the Chasmops limestone.

West Scania.—Turning now to West Scania, we find the best exposures of the Lower Ordovicic strata in the Fogelsång and Röstångo areas. The lower beds are seen only in the Fogelsång region, some 7-8 kilometers east of Lund. Here, too, the exposures are in a measure unsatisfactory, the only natural outcrops being along the Sularpsbäck and the Fogelsångbäck. By digging, however, in the banks along the streams and elsewhere, access was obtained to the underlying shales. Moreover, contacts between the several zones are among the rarities, and thus an element of doubt as to the absoluteness of the succession, made out by the workers in this field, must always remain.

The general development of the Ordovicic is almost exclusively in a shaly phase and the Atlantic graptolite fauna furnishes the dominant organic expression.

The lower zone of the Dictyonema beds with *D. flabelliforme* is seen only in the eastern end in the bed of the Sularps-bäcken south of the hamlet of Mejeri. The beds here include some thin calcareous layers, but they are not seen in contact with the higher beds. The two succeeding zones of the Dictyonema shale, that with *Clonograptus tenellus* and that with *Bryograptus kjerulfi,* are seen only on the Fogelsångbäck, especially near its junction with the Sularps-bäck. The outcrops are, however, discontinuous.

In the banks of the Fogelsångbäck, near the village of that name, digging reveals the upper beds of the Dictyonema zone, and here it is found in contact with the Ceratopyge limestone, both the lower or Shumardia zone and the Ceratopyge limestone proper being represented in

slight thickness. The continuity of the section is interfered with by a diabase dike. Close to this are the strongly metamorphosed Lower Didymograptus beds, with characteristic fossils still recognizable. This same zone appears again farther north on the banks of the Fogelsång brook, where it carries *Phyllograptus cor* Strandmark. These beds are described by Moberg as lying partly under (in the bed of the stream) and partly over (in the E. banks) the Orthoceras limestone. The "Orthoceras limestone" is shown in an old quarry near the brook; the west wall of this quarry shows the lower part of the Upper Didymograptus bed, the zone of *Phyllograptus* cf. *typus* overlying the Orthoceras limestone.[48] "At the bottom of the most southerly limestone quarry, . . . on the occasion when it was pumped dry, a slaty limestone was found, rich in trilobites, among which may be mentioned *Trinucleus coscinorhinus* Ang. and *Aeglina umbonata* (Ang.)." This exposure was not accessible during our visit. It is clear that there is some complication and confusion here, though it would appear that the *Trinucleus coscinorhinus* beds are included in or represented by the whole of the Orthoceras limestone, and that the Upper Didymograptus beds overlie this limestone. If this relation is normal and not due to faulting, it settles the position of the *Trinucleus coscinorhinus* beds as definitely *below* the break.

The Upper Didymograptus beds are well shown in a steep bank on the south side of the Sularp River, just above the mouth of the Fogelsång creek. Both the lower division with *Phyllograptus* cf. *typus* Hall and the upper or Geminus division with *Lonchograptus ovatus* Tull. are here shown, but no higher beds. These beds are also seen farther down the Sularp River at several localities, both in the bed and bank and on the Fogelsång, but as isolated outcrops which show no relation to higher or lower beds. At Sandby West Mills, about 500 meters above the mouth of the Fogelsång, the Lower Dictyonema beds are exposed not far from the Geminus beds, the former being seen in a ditch close to the north bank, the latter in the river bed and in the south bank. A short distance to the west Middle Dicellograptus shales, with *Orthis* (zone of *Ampyx rostratus* Sars. and *Calymene dilata* Tullb. of the Chasmops beds) appear, being brought next to the Geminus beds either by a fault or by the cutting out of the Lower Dicellograptus beds in this region, and an amplification of the hiatus which separates the Lower and Middle Ordovicic series. The Orthis shales are limited above by a diabase dike, 23 meters thick, which has burnt the shales white at this contact.

The Lower Dicellograptus beds are exposed at a number of localities on the Sularp River, both above and below the mouth of the Fogelsång.

[48] Moberg: Guide, p. 26.

The best exposures are in the south bank of the river, from 500 to 600 meters below the mouth of the Fogelsång. Here the lowest zone of the region with *Glossograptus hincksi* Hopk. is seen, but not in contact with any lower formation. A hundred meters or more upstream, however, occurs an outcrop of the Geminus bed of the Upper Didymograptus shales. Since no other formations falling between these two are known in this region, the hiatus (St. Peter hiatus of American nomenclature) occurs in this interval. The lowest zone of the next higher series—that is, that of *Climacograptus rugosus* Tull. (= zone of *Dicranograptus clingani* Carr.) or the Lower Hartfell—is shown in the river bed only a short distance below this.

In the Röstanga district, on the north border of the Ordovicic-Siluric zone of West Scania (38 kilometers north from Lund), we meet with other exposures of these strata, though the lower beds of the Ordovicic are not seen. We did not visit the sections, but they have been fully described both by Tullberg (1883) and by Moberg. There seems to be some confusion regarding the interpretation of the lower beds, but the Orthoceras limestone of this section probably lies above the horizon of the Upper Didymograptus shales instead of below it. The two are not found in the same section, and this interpretation is based purely on paleontologic evidence, the stratigraphic evidence at first sight being against this.

The Orthoceras limestone is seen only in the Kvarnbäcken (Mill Brook), where it forms an isolated outcrop of black, hard, often crystalline limestones, alternating with lighter gray beds, exposed in the bed of the stream and dipping about 45° south. It has yielded a number of fossils: those reported by Tullberg and Moberg being: 1, *Asaphus acuminatus* Ang.; 2, *Æglina umbonata* (Ang.); 3, *Illænus esmarki* Schloth; 4, *Ampyx carinatus* (Ang.) Linss.; 5, *Niobe emarginula* Ang., and species of Ptychopyge, Trinucleus, and Orthis, as well as a Cystid. As Moberg remarks: "The limestone belongs with certainty to the upper part of the Scanian *Orthoceras* limestone (Asaphus beds)" (Guide, page 80). Compared with the Esthonian development, we find that number 3 of the above list characterizes all three divisions of B III, while number 5 is characteristic of B III α and B III β. In Dalarne and Westergotland *Illænus esmarki* occurs in the Asaphus limestone above the Limbata beds and, as I have shown, above the hiatus. By these standards, then, the Orthoceras limestone of Röstanga belongs to the upper part of the Middle Ordovicic, representing probably a part of the Lower Dicellograptus horizon. In the Mill Brook it is followed, after an interval of 400 meters, by hard Orthis shales with *Calymene dilatata* Tull., *Ampyx rostratus*

Sars., and *Orthis argentea* His. These represent the Chasmops horizon of the Swedish succession. Between these two outcrops Tullberg records shales with *Climacograptus rugosus* Tull. and *Cl.* cf. *cœlatus* Lapw. (that is, zone of *Dicranograptus clingani* Carr.), but these have not been found by later observers. In any case the beds recorded above the Orthoceras limestone in this brook belong to the Lower Hartfell horizon or the Middle Dicellograptus beds of Scania.

The Lower Dicellograptus shales are exposed in the Kyrkbäcken (Church Brook) about 500 meters east of the Orthoceras limestone outcrop above mentioned. They dip here at an angle of 40° south, with a strike of north 80° east, which would bring them, as well as the underlying Upper Didymograptus beds, *above* the Orthoceras limestone and below the Orthis shales of the Mill Brook section. The section is apparently a continuous one, the Upper Didymograptus shales with *D. geminus* being succeeded by the Lower Dicellograptus shales with *Climacograptus scharenbergi* Lapw., *Diplograptus teretiusculus* His., *Dicellograptus moffatensis* Carr., *Dicellograptus sextans* Hall, *Glossograptus* sp. *Corynoides calicularis* Nich., and *Primitia strangulata* Salter: also the trilobite *Robergia microphthalmus* (Linrs.). Since it is not likely that the Orthoceras limestone dies out in so short a distance, it must be cut out by a fault in the present section, where the Brachiopod shales (uppermost Ordovicic) come in after only a short interval, though some of the intervening Ordovicic beds are faulted in again beyond this point.

Tosterup.—The estate of Tosterup lies in the southeastern part of the Scanian Paleozoic belt, about 12 kilometers north-northeast of Ystad. The base of the Ordovicic is here the Dictyonema shales which succeed the Peltura zone of the Upper Cambric. No representative of the Ceratopyge beds is found in this region which corresponds thus essentially to the development at Jerrestadt-Tommarp, in East Scania. The Lower Didymograptus shales are poorly exposed, but seem to be conformably succeeded by Orthoceras limestone, which here, as at Tommarp, belongs to the lower division. In it have been found *Nileus armadillo* Dalm., *Megalaspis* (*planilimbata* Ang.?), Agnostus sp., and Orthoceras sp. That higher members of the Orthoceras limestone series may be present is indicated by the fact that Tullberg lists from this rock *Symphysurus palpebrosus* Dalm., *Cheirurus clavifrons* Ang., and *Illænus esmarki* Schloth, species occurring in the Upper Orthoceras or Asaphus limestone of Westergotland and elsewhere.[49] Beds believed to be those of the *Trinucleus coscinorhinus* zone with *Ampyx rostratus* have been reported above the

[49] *Symphysurus palpebrosus* occurs, however, in the Orthoceras limestone of Bornholm with *Megalaspis limbata*.

Orthoceras limestone, while the next higher zone is that of *Dicranograptus clingani* Carr. Here occur, besides the above, *Dicellograptus forchhammeri* Gein., *Climacograptus bicornis* Hall, and *Diplograptus foliaceus* Murch. The evidence from this section would seem to place the *Trinucleus coscinorhinus* zone above the break.

ORDOVICIC OF BORNHOLM [50]

This island forms the southeastern extension of the rock series exposed in Scania. It shows a large area of pre-Cambric rocks on the northeast, and an area of older Paleozoics on the south, and of Jurassic and younger strata in the west. As in Scania, there are numerous dislocations which complicate the succession.

The series begins with the basal arkosic Nexö sandstone, 60 meters in thickness, which corresponds to the Fucoidal sandstone of Sweden. This is conformably succeeded by a green graywacke shale consisting of alternating glauconitic clay shales and sandy shales with phosphate concretions and occasional thin limestones, the total having a thickness of 57 meters. Only *Hyolithes* (several species) and *Torellella lævigata* Linnrs. have been found so far. This, with the basal sandstone, represents a part of the Lower Cambric. The upper part of the series is arenaceous and it is disconformably succeeded by the *Paradoxides tessini* zone of the Middle Cambric, the lower beds of which contain, according to Grönwall, worn fragments of the underlying sandstone. The hiatus here represents the lower part of the Middle Cambric below the Tessini zone. The total thickness of the Middle Cambric, which consists mainly of alum shales, is 4 meters, and it passes conformably into the Upper Cambric Olenus beds, all of the higher Middle Cambric zones being represented. These Olenus shales with the typical Swedish Upper Cambric fauna are 15 meters thick. They are followed, apparently without break, by the Dictyonema shales, with a thickness of 5 meters, which, however, appear to represent only a part of the Dictyonema series. The Bryograptus and Tetragraptus zones are absent, the Orthoceras limestone following directly on the Dictyonema shale, with a thickness of 4 meters. The base of this formation consists of a thin, dark glauconitic limestone layer with much pyrite and numerous phosphatic nodules containing sponge spicules. Desiccation fissures are represented by their ridgelike fillings. The main part of the Orthoceras limestones consists of gray, somewhat nodular, limestone with 10 to 15 per cent clay. It contains numerous trilobites, among them *Megalaspis limbata* Buch., *Ptychopyge applanata* Ang., *Symphysurus*

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[50] In this section I rely entirely on Ussing, Handb. d. Reg. Geol., Bd. I, Abt. 2, Dänemark, 1910, as I have not visited this island.

palpebrosus Dalm., and *Nileus armadillo* Dalm. The formations thus represent the *M. limbata* horizon, but whether the *M. planilimbata* bed is represented in the lower part of the limestone or whether this and the Ceratopyge limestones are wholly wanting does not yet appear.

The limestone is succeeded by the Dicranograptus shale of the lower Upper Ordovicic, corresponding essentially to the Lower Hartfell shales of Scotland. There is thus a pronounced hiatus here, representing the Middle and Upper Arenig and the whole of the Llandeilo. Three zones are represented in the bituminous shales of this series. These are:

3. Zone with *Climacograptus styloides* Lapw.
2. Zone with *Dicranograptus clingani* Carr.
1. Zone with *Climacograptus vasæ* Tullb.

The lowest or oldest of these zones is not known in Scania, where the upper series begins with the zone of *Dicranograptus clingani* Carr. This lower zone, however, corresponds, according to Tullberg, to the zone with *Climacograptus wilsoni* Lapw. in Scotland.

There is thus clearly indicated a general overlap of the advancing Upper Ordovicic series over Sweden, though this was a very irregular one, some portions of Sweden becoming submerged before others.

Summary of the Early Ordovicic Sections

We may now summarize the early Ordovicic sections and deduce from them the sequence of events. Throughout most of western Europe the basal Ordovicic beds lie with a greater or less hiatus on the Upper Cambric or older formations down to the Archean complex. This marks a wide-spread transgression which was inaugurated with the beginning of Ordovicic time, following a previous partial withdrawal of the sea. In the English area alone the sedimentation seems to have been continuous, the Upper Cambric beds being conformably succeeded by the Tremadoc. But even here there may be proved a hiatus by future investigations.

Two main areas of sedimentation are recognizable—the Baltic and the Mediterranean. These were both open to the Atlantic of that period, but were themselves separated by the Old land of Armorica, which extended between them as a peninsula; while the southern or Mediterranean region seems to have been merely an embayment of the Atlantic, the Baltic was for part of the time at least a channel, connecting the Atlantic with the sea then covering part of Siberia.

A third center of deposition in Europe was the North Scottish one and its possible extension in the western Scandinavian region. This district appears to have been entirely separated from the Atlantic Ocean by the

old Caledonian land-mass which extended across the Atlantic to Newfoundland.

The sections discussed clearly indicate that the early Ordovicic transgression of the sea marked an eastward advance of the Atlantic waters along both channels, and with this also a lateral spreading and inundation of the low shores of the bounding lands, namely, Caledonia on the north, Armorica in the center, and probably North Africa on the south, though satisfactory sections of the African region are not available. In the Baltic region the Siberian Sea also transgressed from the northeast, and so a commingling of the Ceratopyge fauna from that region and of the Dictyonema fauna from the Atlantic region took place. The Atlantic fauna seems to have advanced eastward earlier—no doubt owing to the mud deposits which kept out the purer water fauna from the east. Thus when the Ceratopyge fauna in turn advanced with the clearing of the waters, the beds in which it occurs came to overlie the Dictyonema shales. On the margin of the old land the progress of the transgression is indicated by the overlap of the Arenig beds over the Tremadoc, the latter being absent in southern Scotland—the southern border of Caledonia—and in Brittany and Normandy—the northern border of Armorica. In like manner the Ceratopyge beds are wanting or represented only by shore sands in the Baltic provinces of Russia, and they are similarly overlapped by the later Ordovicic beds in Jämtland (Sweden). The Phyllograptus shales of the Atlantic came in contact with the Megalaspis limestones of the Siberian sea and the two likewise interfinger in the Baltic region. In the southern embayment the transgression included northeastern Spain and southeastern France before the end of Tremadoc time, but did not reach Bohemia until well along in Arenig time. When the northern Scottish region and a part of the northern border of Caledonia were submerged cannot be determined with precision, since the Beekmantown fauna, which alone existed there, can not be correlated in detail with the Atlantic or Siberian phases. Most probably, however, the early part of the Durness limestone (exclusive of the Cambric portion below the hiatus) belongs to the period of the Tremadoc and Ceratopyge sediments.

The second great event indicated by the sections is the retreat of the late Arenig Sea, until the Baltic region apparently became entirely dry and the Scandinavian lands were joined to Armorica. The withdrawal was westward to the Atlantic and eastward in the Siberian end of the channel. In southern Wales alone deposition appears to have continued, the Llanvirn series marking a transition from the Arenig to the Llandeilo, but also having distinctive characters, owing to the much contracted character of the embayment in which they were deposited. The Mediter-

ranean also seems to have been laid bare, though future studies in Sardinia and elsewhere may show a similar continuous series. Erosion no doubt occurred in many of the emerged areas, so that a part of the previously deposited Arenig was again worn away. As a result, also, basal conglomerates were formed and incorporated in the higher beds, when the sea again advanced.

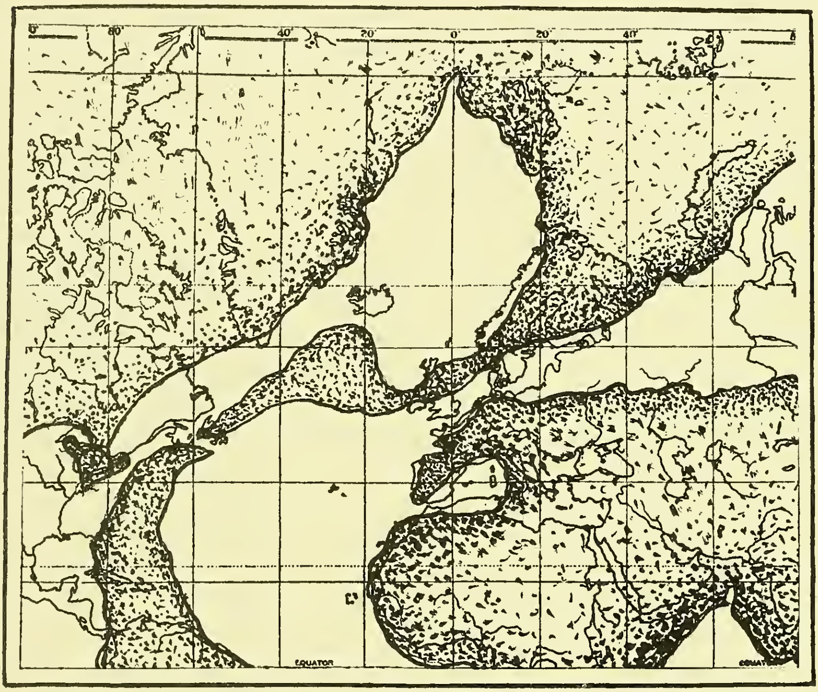

FIGURE 10.—*Paleogeographic Map of eastern America and western Europe and Africa in early Ordovicic Time*

Showing the three principal oceans—the Atlantic or Arenig-Llandeilo sea in the lower part, the Boreal or Beekmantown-Chazy sea in the upper center, and the Siberian sea on the right.

The readvance of the sea was apparently contemporaneous with the whole of Llandeilo and at least a part of Caradoc time. As shown by the different sections, Lower Llandeilo beds succeed the hiatus in some places and Upper Llandeilo in many more. Again, some of the regions were not covered until Caradoc time, as shown by the succession of these beds next above the hiatus. As in previous transgressions, the Siberian trilobite fauna and the Atlantic graptolite fauna came in contact in the Baltic region, where more or less interfingering and overlap of the two series is

recorded. The slow westward transgression of the Siberian Sea in the Baltic is shown by the progressive overlap of the lower by the higher members of the series.

The period of initial transgression corresponds to the Potsdam and early Beekmantown (Little Falls) transgression in North America. The first retreat, in late Arenig time, corresponds to the great Beekmantown retreat and the period during which the St. Peter sands were widely spread over central North America. The readvance during Chazy time corresponds to the readvance in the Llandeilo, and as in that case different members of the Chazy rest on the erosion plane or the reworked St. Peter, the successively higher members of the Chazy overlapping the earlier ones. Finally, the Black River beds overlapped the Chazy and the early Trenton beds in turn overlapped the Black River, as in various portions of the Canadian and the Rocky Mountain region.

It thus appears that these movements were simultaneous in Europe and North America, and that hence they belong to the changes of level due to diastrophism, expressed in the lowering and the raising of the sealevel all over the earth. Accordingly, breaks in the series as here described should occur between the corresponding formations in many other parts of the world. The paleogeographic conditions for western Europe are expressed in the map (figure 10) on the previous page.